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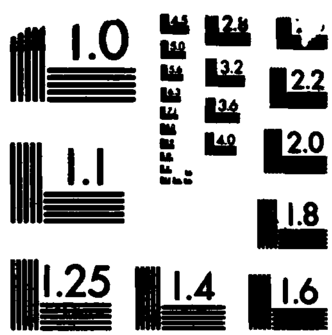

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RADC-TR-83-180
Final Technical Report
August 1983

AD A138576

CONDITION MONITORING TECHNIQUES FOR ELECTROMECHANICAL EQUIPMENT USED IN AF GROUND C³I SYSTEMS

Hughes Aircraft Company

Robert R. Holden

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ROME AIR DEVELOPMENT CENTER
Air Force Systems Command
Griffiss Air Force Base, NY 13441

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Air Force Ground Command, Control, Communications and Intelligence (C^3I) Systems depend on electromechanical equipment to provide their power and control their environment. This report, based on a two-phase 15-month study, describes the vulnerability of C^3I Systems to failures in their electromechanical equipment and the opportunities to meet performance and availability demands using condition monitoring in conjunction with reliability centered maintenance. The initial phase attempted to identify

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the most promising opportunities to apply condition monitoring for diesel generators, motor generators and environmental control units used in radar, intelligence gathering and communications systems. In obtaining the data for the initial phase, a number of shortcomings in the equipment instrumentation, data collection and reporting processes were disclosed and these problems are described. Data was obtained from visits to Air Force user organizations and sites. As a result of the initial phase investigation, the AN/FPS-115 PAVE PAWS radar was selected as the candidate system for the second phase of the effort. The second phase identified specific condition monitoring techniques for the prime power and environmental control equipment used with the AN/FPS-115 PAVE PAWS system. The results of the second phase of the study demonstrate that it is possible to develop a condition monitoring system design for the PAVE PAWS power generation and cooling equipment utilizing state of the art monitoring techniques and sensors.

PREFACE

This report was prepared by the Advanced Technology Projects organization of Hughes Aircraft Company, Long Beach, California, in accordance with Contract Number F30602-81-C-0113 (CDRL Item No. A003) from Rome Air Development Center (RADC), Griffiss Air Force Base, New York.

The RADC project engineer was Mr. James A. Collins (RADC/RBES). The Hughes program manager and principal investigator was Robert R. Holden. The major field effort was accomplished by Mr. Holden and Hughes survey team members H. A. Diede and R. J. Little. The report was reviewed and edited by K. V. Pearson, A. F. Lawrence and R. W. Armstrong of the Technical Audit Team.

A joint Hughes/RADC paper on this study was presented at the Mechanical Failure Prevention Group - Detection, Diagnosis and Prognosis Conference held at La Posada Inn in Phoenix, Arizona (December 1982).

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STUDY OF CONDITION MONITORING TECHNIQUES FOR ELECTROMECHANICAL EQUIPMENT USED IN AIR FORCE GROUND C^3I SYSTEMS - FINAL REPORT

1.0 EXECUTIVE SUMMARY

The accompanying report presents the results of the fifteen month, two-phase study performed by Hughes, to define condition monitoring techniques for electromechanical equipment used in Air Force Ground C^3I Systems. The initial phase activity attempted to identify the most promising opportunities to apply condition monitoring for diesel generators, motor generators, and environmental control units used in radar, intelligence gathering, and communications systems. As a result of the initial phase investigation, the AN/FPS-115 PAVE PAWS was selected as the candidate system for the second phase effort to identify specific condition monitoring techniques. The second phase began with approval of the Interim report which documented the initial phase findings and recommendations.

In obtaining the data for the initial phase, a number of shortcomings in the equipment instrumentation, data collection and reporting processes were disclosed. These problems are described in some detail in the report along with the equipment utilization problems discovered during our user site visits. Numerous attempts to confirm the universality of power and air conditioning problems on AF Ground C^3I Systems were frustrated by delays and gaps in the data provided

by the Maintenance Data Collection System and Air Logistics Centers, making it necessary to visit the Air Force user sites.

These efforts draw on Hughes' automatic test and diagnostic system design experience and numerous machinery monitoring related studies. They address the Air Force need for real time readiness assessment and prediction capabilities to support the operational and maintenance decisions necessary to maintain acceptable C^3I system performance and availability.

Section 2 outlines the objective, scope, overall problem and report organization. Section 3 describes how the initial phase effort was revised and conducted to accomplish the survey. Section 4 covers the initial phase survey, excluding PAVE PAWS. Section 5 presents and analyzes the data collected from the PAVE PAWS survey. Section 6 describes PAVE PAWS prime power generation and cooling equipment and the associated failure modes. Section 7 presents the development of a condition monitoring system, including techniques and sensors, for the PAVE PAWS prime power generation and cooling equipment. Important peripheral conclusions and recommendations are presented in the related discussions throughout the report. Prime conclusions and recommendations are made in sections 8 and 9, respectively. A glossary of abbreviations may be found in the appendix along with a bibliography and other reference material.

BACKGROUND

Several industry and government programs have demonstrated that on-line monitoring can increase the effectiveness of manpower in both maintenance and command decision roles. Monitoring of systems has been particularly effective when applied to large deployed high technology systems, including aircraft, ships, and tanks, where automated manpower aids are mandatory. The question addressed in this study is: whether, where, and to what extent condition monitoring is warranted for Air Force Ground C^3I Systems.

Condition monitoring, when introduced into a system, affects the entire Integrated Logistics Support (manuals, maintenance, training, etc.). When introduced early enough, it should also impact the system design by forcing the designer to consider problems that are often deferred or ignored. Design deficiencies are best remedied by design improvements, not by condition monitoring. Design problems can dilute or even negate the potential condition monitoring benefits. The same is true of installation problems. Some logistics support problems are reduced or eliminated by condition monitoring while others are intensified, perhaps because they become easier to identify and categorize. We must recognize that for the cost of ownership to be lowered while ensuring adequate life cycle performance, design and implementation costs are bound to increase, however shifting the cost up front will pay off continuously over the lifetime of the system.

Several areas that appear unrelated to power and air conditioning become candidates for monitoring when the condition monitoring systems engineering analysis is performed. We have therefore been careful to include as much information as possible on the vulnerability of the prime systems to non-combat related equipment outages (soft kills), design problems and support problems, so that when the systems engineering is done for the selected system, the impacts and interrelationships of these problems would not be overlooked.

SUMMARY OF CONCLUSIONS

- It was possible to develop a condition monitoring system design for PAVE PAWS prime power generation and cooling equipment, utilizing state of the art monitoring techniques and sensors.
- In the absence of condition monitoring, the vulnerability to failures in diesel generators, motor generators, and environmental control units constitutes a real threat to C^3I system readiness and availability.
- Along with their growth in sophistication, modern military systems tend to be less tolerant of excursions from the power and environmental norms specified in the design.
- The electromechanical equipment is not sufficiently instrumented to produce the engineering data required for characterizing failures.
- The Maintenance Data Collection System (MDCS) data products provide little definition of failures occurring at the electromechanical subsystem level within Air Force Ground C^3I systems.

- The item managers for electromechanical equipment lack the visibility on how failures in the diesel generators, motor generators, and environmental control units impact specific C^3I missions.
- Several current Air Force Ground C^3I Systems designated in the report could profit from the results of this study. Most of these would make equally viable candidates for establishing condition monitoring techniques.
- PAVE PAWS (Beale) would probably have detected the suspected misalignment responsible for premature failures of two diesel generator pedestal bearings had condition monitoring been employed.
- Condition monitoring can not only predict, detect, and isolate failures, it can verify installation integrity and confirm successful repairs. Combined with Reliability Centered Maintenance, it can help conserve maintenance resources and reduce maintenance-induced failures.
- Condition monitoring is not a panacea, it is a tool. Unmittigated design and maintenance resource deficiencies can defeat the best of tools. Several such deficiencies have been identified in this report.
- The success of condition monitoring depends on having all the other logistics support elements in place including spare parts, repair skills, technical data, etc. In other words, detection, diagnosis and prognosis tools must be complemented by the means to fix and prevent problems.

SUMMARY OF RECOMMENDATIONS

- Operate PAVE PAWS with computers on diesel generated power, and radar on commercial power, to eliminate radar generated EMI. This saves the money which would be used to switch commercial power sources at Otis, and improves the condition of the diesels by reducing deterioration from disuse.
- Allocate funds for a follow-on effort to breadboard, test, and evaluate the condition monitoring techniques established in this study. Conduct the breadboard evaluation on a diesel generator, motor generator, and environmental control unit at a PAVE PAWS-like site.
- Expand the current effort to include survey of additional key Air Force Ground C^3I Systems including ESC Systems, JSS, NORAD-HQ, SEEK IGLOO, GEODSS, et.al.
- Consider the merits of introducing a diesel engine analyser to the depot, based on Long Beach Naval Shipyard and industry experience.
- Consider providing Civil Engineering Maintenance, Inspection, and Repair Teams (CEMIRT) with a portable diesel diesel engine condition analyser which could distinguish between diesels that can be repaired in-place and those requiring removal for overhaul.
- Fund a similar effort directed toward tactical ground C^3I systems that acknowledges the differences from strategic counterparts including: function, equipment design, operat-

ing environment, and operation and maintenance manpower skills.

- Extend the condition monitoring investigation to tactical and strategic airborne C^3I systems.

2.0 INTRODUCTION

2.1 OBJECTIVE

The initial phase study objective was to review the types of electromechanical equipment used in Air Force Ground C^3I Systems and to determine the most promising candidates for applying condition monitoring techniques.

The second phase objective was to identify the critical parameters to be monitored and the design techniques required to monitor these parameters for the selected system.

2.2 SCOPE

The electromechanical equipment reviewed for applicability of condition monitoring includes diesel generators, motor generators, and environmental control units. The C^3I ground systems include radars, intelligence gathering systems, and communications systems.

2.3 OVERALL PROBLEM STATEMENT

National security is weakened immeasurably whenever any C^3I system goes out of commission, or is forced to operate with reduced capability. Consequently, elaborate security precautions protect these systems from <u>external</u> threats to minimize their vulnerability to compromise or sabotage. This study examines the opportunities to

reduce their vulnerability to internal threats posed by degradation or failure of electromechanical equipment, by employing condition monitoring. The specific types of electromechanical equipment studied are: diesel generators, motor generators, and environmental control units.

Several factors contribute to the vulnerability of military equipment:

- Increased tempo of operations
- Loss of experienced skilled personnel
- Greater dependency on clean power and controlled environment
- Reliance on calender-based maintenance
- Limited means of fault diagnosis and prognosis

Advances in technology continue to shorten the time available to react to events and still influence their outcome. This quickening tempo of military operations magnifies the impact of brief system outages and makes long unscheduled outages intolerable. When heavy machinery breaks down, the mission might be over before the repair is completed. In fact, unless it gets back on line fast it could miss an entire war. Excessive down times can be minimized by avoiding their causes and keeping problems small. This means attacking them before they lead to catastrophic failure. Any true solution must reduce the high incidence of maintenance-induced failures and correct design and installation deficiencies. Furthermore, greater need for system Built-In Test and on-line system readiness assessment

capabilities exists today to reduce the system vulnerability to so-called, "soft-kills", and permit reconfiguration for use following damage from battle and acts of vandals or terrorists.

Greater use of automation is seen as a panacea by some, and as just the opposite by others. The ATE (Automatic Test Equipment) community condition monitoring proponents advocate a systems engineering approach that addresses and satisfies all the operational and logistics support elements and constraints.

Condition monitoring can reduce soft-kill vulnerability by providing the means to detect, diagnose, and predict failures in the electro-mechanical equipment. When used in conjunction with Reliability Centered Maintenance (RCM), it can reduce the incidence of maintenance-induced failure and permit the shift of preventive maintenance from calendar-based scheduled maintenance actions to "on-condition" maintenance. RCM is the DoD adaptation of techniques practiced by the airlines. The combined benefits of improved availability, readiness, and survivability, with reduced maintenance resources consumption can be projected when condition monitoring, reliability centered maintenance, and adequate systems engineering are combined.

3.0 DATA COLLECTION OVERVIEW

This study set out to identify electromechanical equipment failure impact on C^3I availability, high maintenance resource consumers, failure parameter monitoring needs, viable candidate equipment for monitoring, the most effective monitoring techniques available, and the need for developing new condition monitoring techniques. The methodology outlined in Figure 3-1 was developed to ensure that these goals would be met. This section describes some of the difficulties encountered and adjustments made to acquire data sufficient for identification and selection among candidate equipments and obtaining RADC concurrence.

3.1 DATA SOURCES

3.1.1 Logistics Command

A pilot survey and analysis was conducted to validate the original methodology while conserving study resources. Accordingly, visits were conducted to Sacramento and San Antonio ALCs and AFLC Headquarters. The expectation was to obtain failure histories and statistics from the Maintenance Data Collection System (66-1 reports) and from the organizations responsible for diesel generators, motor generators, and environmental control units. The pilot study determined that this approach could not produce the data necessary to proceed with the original plan. Too much of the required information never gets back from the users to the depot or into the data base. Consequently, the plan was revised to obtain the data from the users by visiting selected C^3I system installations.

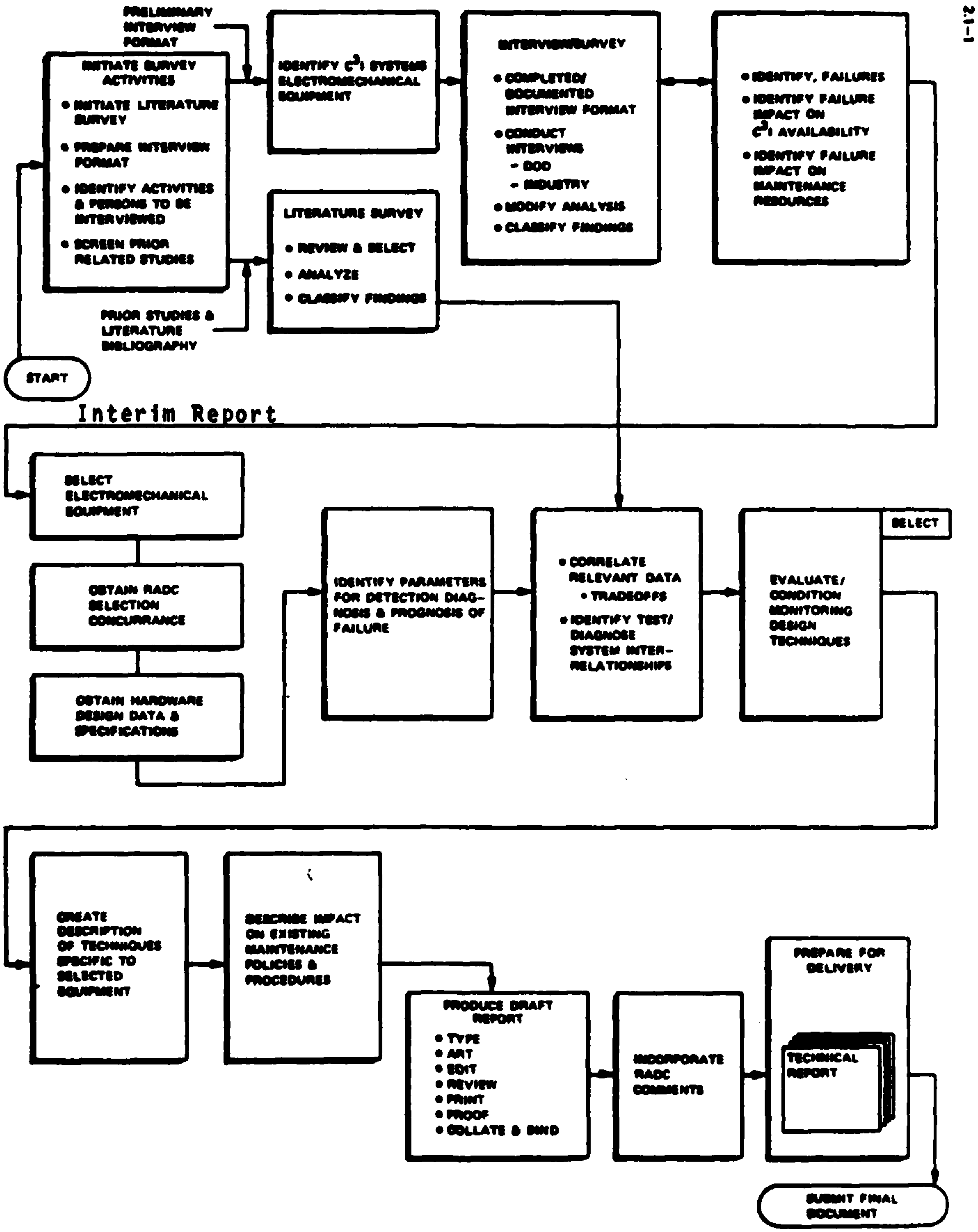

Figure 3.1 STUDY METHODOLOGY

3.1.2 Communication Command

As a result of the support received from S-ALC, an inquiry was made to the Air Force Communications Command (AFCC) Headquarters (AFCC-HQ). AFCC/LGMKE provided Equipment Status Reports (ESRs) covering 18 months, listing RED (total) and AMBER (partial) outages attributed to power and environmental control for NAVAIDS and airport surveillance radars. The data was summarized by Air Force Base and by nomenclature for all such systems under their cognizance. Copies of this data were provided RADC/RBES along with the summaries by equipment and failure type, (cf Interim Report Appendix).

3.1.3 Electronic Security Command

During the pilot study, attempts were also made to obtain data from the Air Force Cryptologic Support Center (AFCSC) on the impact failures in power and environmental control have on their C^3I missions. We received no data from AFCSC. AFCSC revealed that they do not use the ESR system and have no means to document the historical relationship of such failures to RED and AMBER conditions for their C^3I systems. It was therefore concluded that only by interviewing ESC C^3I systems users could we obtain the required data. Subsequent to our visit, AFCSC sent a letter which referred us to the Electronic Security Command (ESC) Headquarters. ESC/LGMQ agreed to identify user contacts for interview such as personnel returning from overseas where their SIGINT/ ELINT sensor systems are deployed. Seven months later several contacts were identified by ESC, however the travel budget was long since depleted, making a visit impossible without

additional contract support. During the review period for the initial submittal of this report, ESC/LGM provided a detailed letter confirming that power and air conditioning problems require heroic efforts of their people to keep missions up. A copy of this letter appears in Appendix C.

3.1.4 Tactical Air Command

Inquiries to the Tactical Air Command Headquarters revealed that most of their operational C^3I systems are outside CONUS. There was no budget for overseas travel in this study. Furthermore, they revealed that the Reliability Analysis Center (RAC) at RADC was conducting a survey with them that seemed to duplicate our needs. We therefore concentrated on domestic strategic systems and requested RADC to provide the RAC survey data. A draft of the RAC final report was received subsequent to the survey period. While the RAC report supported our findings with respect to the difficulties of collecting data, the data itself was of little consequence to this effort.

3.1.5 Strategic Air Command

While many of the strategic C^3I systems are located abroad, budget and schedule constraints limited the selection of candidate systems to those within CONUS. RADC/RBES identified surveillance radars as the highest priority C^3I systems to be investigated. PAVE PAWS (AN/FPS-115) was selected as representative of surveillance radars employing current technologies.

Although older systems, such as the "Fuzzy Seven" (AN/FSS-7) might have provided longer histories with better statistics, it was felt that their experience would be more difficult to relate to current and future systems that no longer employ vacuum tube technology.

A local SAC base was visited to follow-up on the NAVAIDS and airport surveillance radar data provided by AFCC-HQ and to investigate any other possible C^3I system study opportunities.

3.1.6 Summary of Visits

The following table identifies the ten Air Force installations and organizations visited during the initial phase. Only the first three visits had been envisioned at the offset of the contract.

The revised plan called for visits to local Air Force Bases to substantiate the data provided by AFCC and to both PAVE PAWS sites. SAC and AFLC Headquarters were also visited to fill gaps in the data. The revised approach proved to be much more successful.

3.2 FAILURE DATA INTERPRETATION

It would be unrealistic to extrapolate an electromechanical equipment condition monitoring need for the newer solid state systems, based uniquely on the experience of older vacuum tube systems. Newer systems like PAVE PAWS, however, are either few in number or still being deployed. Furthermore, they have not been operating long enough to generate sufficient data for good statistics. The failure data

Table 3.1.6-1. VISITS

LOCATION	DATES	DESCRIPTION
Griffiss AFB RADC/RBES	29 April 1981	Kick-off meeting with sponsor
McClellan AFB S-ALC/MMIRM MMCRAB	15-17 June 1981	Electromechanical equipment depot
Kelly AFB SA-ALC/MMIRGA	27-30 July 1981	Electromechanical equipment depot
Kelly AFB ESC/MAVA	30 July 1981	AF Cryptologic Support Center
WPAFB AFLC/LOEP	19 Oct 1981	Maintenance Data Collection System Files Manager
Griffiss AFB RADC/RBES	20 Oct 1981	2nd Quarter Review Meeting
Otis AFB 2165th CS MWS/DE	28-29 Oct 1981	PAVE PAWS (EAST)
Offutt AFB SAC/DCLC SXOG CE	30 Oct 1981	SAC HQ PAVE PAWS Item Manager
Beale AFB 2156th CS 7th MWS/DE, CE	16-17 Nov 1981	PAVE PAWS (WEST)
March AFB 15th AF 33rd CG/LGM CEM	8 Dec 1981	NAVAIDS SAC COC

from the early operation of new systems must be used with caution to support an argument for, or against, condition monitoring. The data might be biased by infant mortality, design deficiency, or installation related failures that are subsequently corrected. Furthermore the early failures may not correspond to mature system failures that occur when parts start fatiguing and wearing out.

Unfortunately, withholding judgement until better statistics become available is untenable for several reasons:

- By the time good statistics are available, the system could be obsolete, or at least beyond retrofit.
- The systems are currently improperly instrumented to produce the real time operating data for characterizing failures. Such engineering data is necessary to identify failure modes and effects, develop failure statistics, and distinguish design/installation problems that can be corrected independent of condition monitoring.

The absence of good failure statistics and engineering data forces a more pragmatic approach.

a) <u>Limited Sampling</u>

Condition monitoring needs to be installed on a limited trial basis to provide the missing data and to ensure that its benefits are available to the Air Force before it becomes too late to begin implementation. We need to <u>apply</u> what we already know. This conclusion is supported by the findings of the Industry/Joint Services ATE Project

Task Group on Non-Electronic Testing (op, cit.) as reported to the Joint Logistics Commanders (JLC) panel on Automatic Testing.

b) Establishing Proper Techniques

Condition monitoring needs to be "wrung-out". That is, it needs to be matched to the system, environment, and emerging logistics support methods and procedures. Otherwise the benefits could be outweighed by its burden on the already strained maintenance resources.

c) Improving Record Keeping

The deficiencies in the data collection systems will continue to thwart statistical surveys unless, and until, the deficiencies are recognized and removed. Software should be developed that accomplishes checks and balances on the data base to question, if not correct, obvious errors. For example, the computer should reject faulty part numbers, work unit codes, how failed codes, etc. The ultimate solution envisioned would eliminate paperwork by having the failure data input directly on a computer terminal. Displayed on the terminal, a menu listing the input options with appropriate prompts to the operator, would guide him through the process much as the automated teller machine does for bank customers.

Still unanswered by PAVE PAWS, ESC, and other sources is the question, "If you were to compare the frequency and downtimes with other causes, where would the combined and separate causes due to power and cooling rank, for unscheduled outages to your system?"

3.3 APPROACH TO SELECTING CANDIDATE EQUIPMENT

Determination of the electromechanical equipment used in Air Force Ground Electronic C^3I systems most promising for the application of conditions monitoring resulted from analysis of the potential benefits in terms of improved material condition, increased readiness and reduced maintenance burden.

The data collected in the surveys and interviews provided the information from which a detailed analysis attempted to deduce the relative importance of the selection criteria for each specific electromechanical equipment identified. The contribution to C^3I System downtime of each equipment is important, not only in terms of its contribution to overall MTBF and MTTR, which has significance in peacetime and during extended military exercises, but also for the worst case situation such as during a surprise attack. Potential benefits will accrue in reduced life cycle costs/cost of ownership rather than an immediate reduction in maintenance manhours. In fact, Hughes experience is that when better diagnostic capabilities are introduced into the support of military hardware, spare parts utilization and maintenance manhours often initially increase; however, the performance and the rate of successful repairs also goes up and the equipment fails less often.

As the material condition and readiness of the equipment improves and as the test/diagnostic hardware and procedures mature, the consumation of maintenance resources taper off below the initial rate. Condition Monitoring would be best applied where there are multiple identical opportunities to apply the technique. Such opportunities will probably provide the best failure statistics. However, this should not be subordinated to a single usage that would enhance our defense posture by keeping a critical C^3I System up when it is most needed.

4.0 AF GROUND C^3I SYSTEMS SURVEY

This section describes the information and presents the data obtained during the initial phase of this study. Not only was this the basis for the initial phase selection of equipment, it was part of the data base necessary to conduct the second phase. The PAVE PAWS Survey and Analysis data has been extracted and is presented in sections 5 and 6. A discussion of why PAVE PAWS was chosen is presented in section 3.1.5.

The basis for several of the Conclusions and Recommendations is the information collected from the various Air Force organizations telephoned or visited during the initial phase of this study, as summarized in the following paragraphs. This section presents the information obtained through the ALC's, AFCC Headquarters and March AFB (a local SAC base).

4.1 AFLC ELECTROMECHANICAL EQUIPMENT INFORMATION

4.1.1 DIESEL GENERATORS (FSC 6115)

The survey team led by R. Holden visited Sacramento Air Logistics Center to obtain failure data on the generator sets used in Air Force Ground C^3I Systems. This visit revealed a great diversity in the manner in which generators are managed and the peculiarities which frustrate attempts to extract data using the normal System Reporting Designator (SRD) codes.

Attempts to extract data from the MDCS using the SRD were fruitless until it was discovered that the data was listed by Federal Item Identification Number (FIIN). Implementing the alleged plan to transition from FIIN to SRD would eliminate this difficulty in future searches. (FIIN becomes NSN (National Stock Number) when the two digit country code is inserted after the class code.)

Diesel generators are managed by Sacramento ALC (S-ALC). Formerly, the diesels were separated and sent to San Antonio ALC, (SA-ALC) for overhaul. At the time of our visit, a transition was underway moving overhaul of diesels from Kelly AFB to Mc Clellan. S-ALC now operates the depot for diesels.

Sacramento ALC indicated that the prime motor generator problem component is bearings, followed by governors, contactors, and electronic boards. The bulk of the circuit board problems were attributed to manufacturing defects.

S-ALC reported that the standard DoD generator sets were being phased-in to replace peculiar commercial equipment. Subsequent investigation showed that this was true of the NAVAID's installations, but did not apply to either PAVE PAWS site.

Air Force Ground C^3I Systems operate on commercial power most of the time. When potential commercial power loss is anticipated, the switch to local generated power is made. This happens when weather warnings or alert exercises go into effect. Circumstances usually permit the commercial-to-local generated power transition to take

place over several minutes, during which time all the precautions to protect the generating equipment can be accomplished.

When a drill or true alert is announced, or if commercial power is degraded or lost without such warning, some of the precautions such as powering the water jacket heaters, are deliberately by-passed to get the system up with minimum delay. But, when power goes down, the heat load gets ahead of the cooling because the chillers and chilled water pumps don't operate. When power comes back on, it takes a while before the chillers can catch up to the load to bring the environment of the electronics back within acceptable temperature and humidity operating tolerance limits. The mission RED time thus extends beyond simple restoration of power. Furthermore, the longer the power is down, the longer it takes for the chillers to recover.

The list of diesel part numbers and diesel nomenclature provided by S-ALC appears in Appendix E.

The following Table 4.1.1-1 tabulates the frequency distribution among 79 failures against 29 components in 136 units of the Hobart model 90G 20P, reported over an 18 month period ending 10 December 1980. The data was provided by Sacramento ALC/MMIRM.

Table 4.1.1-1

HOBART 90G 20P

RANK (level)	ITEM	NUMBER OF FAILURES
1	Starter Solenoid	10
2	Starters, Engine	9
3	Water Pumps	8
4	Starter Relays	5
5	AC Voltage Regulator	4
5	Eng. Temp. Switch	4
5	Oil Press Switches	4
5	Electric Governor Top	4
6	Temp. Gauges	3
6	Time Delay Module	3
6	Eng., Rear Oil Seal	3
7	Static Freq. Control	2
7	K17 Relay	2
7	Tach. Cable	2
7	Water Temp Gauge	2
8	Ac. Line Contactor	1
8	Hourmeter	1
8	Fuel Tank	1
8	Eng. Alternator	1
8	Shutdown Switch	1
8	Exhaust Pipe	1

8	AC Generator	1
8	Fuel Pump	1
8	Muffler	1
8	Radiator Core	1
8	Interlock Relay	1
8	Engine Coolant Thermostat	1
8	Undervoltage Module	1
8	Over/under Freq. Module	1
	TOTAL	79

4.1.2 ENVIRONMENTAL CONTROL UNITS (ECUs) - FSC 4120

Often, the ECU is not designated part of the system itself, but part of a shelter managed either by Sacramento ALC or Ogden ALC. Such systems include photo shops, NAVAIDs, and COMM shelters. These ECUs likely appear under the shelter system in the MDCS, separate from the rest of the ECU inventory.

4.1.2.1 Refrigerant Tank Rupture problem.

A refrigerant tank rupture problem was being worked by SA-ALC. Had monitoring instrumentation been in place when these ruptures occurred, the missing engineering data that would permit diagnosis would be available. Extensive data provided by SA-ALC was forwarded to RADC/RBES following the visit to San Antonio. No satisfactory explanation for the several violent rupture occurances was encountered. Fortunately no injuries from the shrapnel had been reported.

4.1.2.2 Failure Data

The current overhaul contractor for air conditioning is based in San Antonio. Local contractors maintain some air conditioners at almost all domestic bases. In these cases no failure information gets into MDCS. 649s are not turned in for depot level overhaul by any contractor. A list of ECUs managed by SA-ALC/MMIRG can be found in Appendix F.

4.1.2.3 Loss of Refrigerant

Loss of refrigerant is expensive, and potentially dangerous. Recently lives were lost on a US Navy ship when a refrigerant line leak developed. Refrigerant could also be a long lead item at remote locations.

4.1.2.4 Legionnaires' Disease

Air conditioning/ventillation systems have been identified by the Center for Disease Control in Atlanta as participating in the cause of this affliction. The Air Force should ensure that adequate precautions are taken to prevent the conditions favorable to its occurrence.

4.1.2.5 Asphyxiation

The common practice of using ground air conditioning carts from the flight line for emergency cooling of buildings has been found potentially dangerous. An incident recently occurred at China Lake

in which such use is alleged to have caused the asphyxiation of scores of people when a shift in the wind diverted the gas turbine engine exhaust into the intake, pumping odorless CO and CO_2 throughout the building.

4.2 NAVAIDS/AIRPORT RADARS

All NAVAIDS at March AFB operate on commercial power with individual automatic starting diesel generators as backup. All diesel generators for NAVAIDS are DoD standard except GCA RAPCON Tower (KATO). To save fuel, diesel generators are run up monthly vice weekly. Bi-weekly they are given a visual check, and run up (no load) for 5 or 10 minutes. Monthly they are operated with load for one hour.

TACCAN/MB-18 ENGINE GENERATOR

Diesel generator uploads in 10 seconds. It's rated for 30 KW, but uses 2KW. (2KW doesn't even show up on the meter)

Localizer/MB-19 Engine Generator

Glide slope/MB-19 Engine Generator (had MB-17 on line while MB-19 down for repairs)

GCA/MB-17 Engine Generator and Carrier 50 EP00856RC air conditioner

Note: glide slope and localizer each have a battery power back-up.

4.3 COMBAT OPERATIONS CENTER (COC) (15th AF-SAC)

The technical load is supplied 150 KW by the rotary UPS. A 750 KW Enterprise diesel generator supplies the utility load.

Diesel generators are given a monthly load test for two hours. These units are monitored separately from Power Production Shop by the communications group.

Chillers consists of two 366 Ton Carrier 19C5J5 units. One is kept on line and the other used for back-up. Temperature of the chilled water supplied by the chiller is 45^{O}F.

4.4 JSS REGIONAL OPERATIONAL CONTROL CENTERS (ROCC)

The following preliminary information was obtained within Hughes for the March AFB location electromechanical equipment, scheduled for 1983.

Generators: KATO, 4P-2250, Type 2124A, Model 600-483361111.

Diesels: Caterpillar, 349JWAC

Air Conditioning: Carrier Chiller, 30HR050

Air Handlers: Robertshaw, A-39D57

A-39ED32

A-39ED38

Condensor Water Treatment: MONGUE

Pump: Phrush

Power: Baltimore Air Coil, VAC-70

4.5 SYSTEM DESIGN PRACTICES AFFECTING PERFORMANCE

Perhaps the single most influential factor that has delayed introduction of condition monitoring into military surface C^3I and weapons systems is the practice of supplying electromechanical sub-systems and components as GFE (Government Furnished Equipment). When the prime system contractor is made responsible for all parts of the system including power and cooling, such as with aircraft and space vehicles, we find that the electromechanical sub-systems are better instrumented and more compatible with the electronics. When the system specifications cover the power and cooling, the trade studies necessary to match the hardware design and installation to the need are more likely to be accomplished. When the system specifications do not cover power and cooling supplied GFE, the trade studies and interface problems get less attention and the economy from designing problems out, is lost.

5.0 PAVE PAWS (AN/FPS-115) MISSION/DESCRIPTION

Primary Missions:	Missile Warning	(1)
	Data Lines	(Z)

The missile warning capability includes detection and tracking of submarine launched ballistic missiles and location and tracking of low altitude satellites. The data lines mission involves data communications specific to NORAD. When (Z)'s status goes RED, (1)'s status is automatically designated YELLOW. When (1)'s status goes RED, (Z) is shutdown (made RED deliberately) to ensure that no bad data is passed. System status and radar data is passed to SAC Headquarters and to the National Command Headquarters in Washington and its ground and airborne alternates.

The principal study concern related to PAVE PAWS performance is how electromechanical equipment failures impact these two primary missions.

The AN/FPS-115 radar phased array consists of 1792 individual crossed dipole elements, mounted in an octagon on each of two faces of a ten story truncated pyramid building. Within the range of the radar, objects with a one meter cross section are detected and tracked. The-field-of-view describes a three thousand mile cone that overlooks all the ocean within range off the east and west coast. The radar can search and track numerous separate objects simultaneously by correlating and processing the return signals, in conjunction with controlling the rate/phase/amplitude of signals transmitted by single

elements (and blocks of elements) in the array. The peak output power level could approach a megawatt if the option to double the number of dipoles is exercised.

The transmit/receive modules are mounted on water cooled heat sinks and require continuous flow of chilled water for heat removal. On the surface, the east and west coast PAVE PAWS installations are identical. From the perspective of this study, however, the differences are significant in the electromechanical equipment area.

5.1 SURVEY AND ANALYSIS

5.1.1 Diesel Generators

Each PAVE PAWS site has six NORDBERG FS-138-ISC diesels,each rated at 1450 horsepower full load. These engines have eight cylinders each in a straight block; the cylinders have a 13-1/2 inch bore, 16-1/2 inch stroke. The diesels are started by compressed air and operate at 450 RPM. They use an Elliott turbocharger (exhaust gas driven). The diesel water jacket nominal temperature is 110^{o}F. The six generators at each site were built by Electric Products, with the exception of one Allis Chalmers model located at Beale. They are rated around 1020 KW, 2400 Volts, 3-phase (1275 KVA, 360 A). A bank of wet cell batteries is maintained to provide the field.

Nordberg now belongs to RexNord, Inc. The address is:

RexNord, Inc.

Nordberg Machinery Group

3075 S. Chase Avenue

Box 383

Milwaukee, Wisconsin 53241

The manufacturer's code has thus been changed from 89798 to 43952 since the diesels were originally built in 1955. They were brought back from South East Asia and rebuilt for PAVE PAWS because replacement cost is on the order of six times the overhaul cost.

Annual usage of the diesel generators varies between 300 and 400 hours. Power plant operating time is on the order of 600 hours per year. The site normally operates off commercial power and uses the generators when commercial power is lost or the site goes on alert.

Three generators are required to operate the technical load successfully. With two units, the observed frequency deviates from 60 Hertz by 0.6 to 0.8 Hertz, with excursions up to one Hertz. With three units on line, the observed fluctuations remain within 0.3 Hertz of 60 Hertz. The UPS (Uninteruptable Power Supply) system is reported to be set to kick-in when the frequency deviates by 0.4 Hertz, which shuts down the site. This precludes operating with only 2 units on the line. But with three diesels on the line, the individual diesels are not adequately loaded. (Only 1/3rd to 2/3rds of rating.) This means that the cylinders carbon up. Oil dilution also results. Furthermore, it's difficult to sync up underloaded

diesels to the commercial line . Also reported was that maintaining proper temperature for both oil and water is mutually exclusive This could have serious consequences if it alters the oil viscosity to where lubrication is degraded.

The Nordberg diesels are adjusted using the site as the load. This is unsatisfactory because the load is either too small (with the radar off), or it is changing too rapidly to permit controlled adjustment of the governor and the fuel racks.

One common design practice that leads to failures we investigated at the PAVE PAWS installation is the use of fuel to cool the lube oil (and the oil to preheat the fuel) directly through a heat exchanger. Such heat exchangers are prone to leak with age. When fuel is cut off to stop the engine, the lube oil eventually penetrates the fuel line and the diesel continues to run by burning its own lube oil until it self-destructs. Although this specific situation was found not to apply at PAVE PAWS, a variation on this type failure could still occur. When oil dilution wears out piston rings, lube oil can wet the cylinder walls sufficiently to keep the engine running after the fuel is shut off. The engine thus consumes the lube oil and self-destructs, unless the air supply is blocked. Since no emergency air cut-off exists,one per diesel is recommended.

The back-up air compressor, which is required to light-off the NORDBERG diesels is motor driven with a small diesel as a back-up.

According to civil engineering at SAC-HQ, there are eight Nordberg diesels like those at PAVE PAWS located at Vandenberg AFB. This information could be useful should we wish to expand our data base on this equipment, apply lessons-learned or transfer technology.

In addition to the six 1000 KW diesel generators and the air compressor diesel at the PAVE PAWS sites, there exists two smaller diesel driven devices. The 116KW unit serves as an emergency generator, which operates emergency lighting and the elevator. The other runs the fire pumps. Only the emergency generator has a load bank which can be used to test and adjust the unit. Only Otis has heaters on the array face which could be used to load the Nordberg diesels to get the % load closer to capacity when adjusting the fuel racks and governors.

5.1.2 CHILLERS

Two 600 ton R-12 Carrier Model 191 EA46-644 chillers are installed at each PAVE PAWS site. Only one is required to carry the load. The second unit is used as a backup.

The chillers operate on the 2400 volt, 3 phase power line. The WUC is 31 P6-2FPS 115-04. 2350 pounds of R12 refrigerant are required to charge each chiller. If power goes down, the recovery time to get the chilled water temperature back to normal is on the order of 10 to 15 minutes from the time power is restored. The time for the electronics temperature to recover can be considerably longer.

Moisture above a few parts-per-million in the refrigerant causes corrosion and degrades performance in air conditioning plants. The chilled water and water cooled condensor design increases the probability of moisture-related failure by several orders of magnitude. When a chiller or condensor tube fails, the refrigerant loop can become heavily contaminated with water. The site's 5 cfm (cubic feet-per minute) vacuum pumps are probably an order-of-magnitude undersize for pumping down such large chillers below the vapor pressure of water within a reasonable time to eliminate moisture. Suggest MIL-stripping for each site from surplus, a pair of larger 2 stage pumps with gas ballast (for pumping moist air), one for on line and one for backup.

5.1.3 MOTOR GENERATORS

The motor generators (MGs) are sensitive to the fluctuations caused by the radar and become much noisier when the transmitter is operating. Frequent failure from warping of the motor-to-generator shaft coupling has been attributed to the continuous speed shifts experienced when the radar is on. A half cycle fluctuation has been measured during transmitter operation at Otis. The 60 Hertz MG sets are hooked only into the lights and Facility Management System (FMS). Each Cyber operates on one of a pair of 400 Hz motor generators. These 40 KVA rated MG sets operate directly from the 60 Hertz power mains without conditioning from the UPS (Uninterruptible Power Supply). It is planned to add a 3rd unit at each site for a back-up.

5.1.4 FACILITY MANAGEMENT SYSTEM

4995-6-97-5158-1 (Raytheon Model OK-340/FPS-115)

The PAVE PAWS FMS Delta 2000 provides each site with a monitoring, alarm and control capability which could be expanded to support condition monitoring and real time readiness assessment. The functions of the FMS as currently installed are shown in the block diagram, Figure 5.1.4-1. Over 200 points are monitored continuously by the Central Processor Unit. Abnormal conditions are printed out as alarms. The MMCO (Maintenance Monitor Console Operator) manually records alarms and return-to-normal conditions on the Job Control Log permanent record (the FMS paper printout is eventually discarded). Twenty-three remote Data Gathering Panels (DGPs) interface the Command Functions, Fire and Security Sensors, Alarms, Analog Monitors and Periodic Programming (switchover) of electromechanical equipment to the FMS Central Processor Unit (CPU) located in the TOR (Tactical Operations Room). There are 112 alarm points (36 fire locations), 26 on/off status points, 32 operating time (hours) readings, 8 temperature sensors, 4 open/close status points, 2 relative humidity sensors and 1 barometric pressure sensor monitored. The FMS solid state memory stores the program for monitoring, controlling, alarming and printing, but does not retain any of the data.

The following table lists the existing FMS monitoring points by the assigned point numbers used to identify alarm locations from the printout. The table identifies the function and parameter monitored plus card cage and DGP designation for troubleshooting. This rather

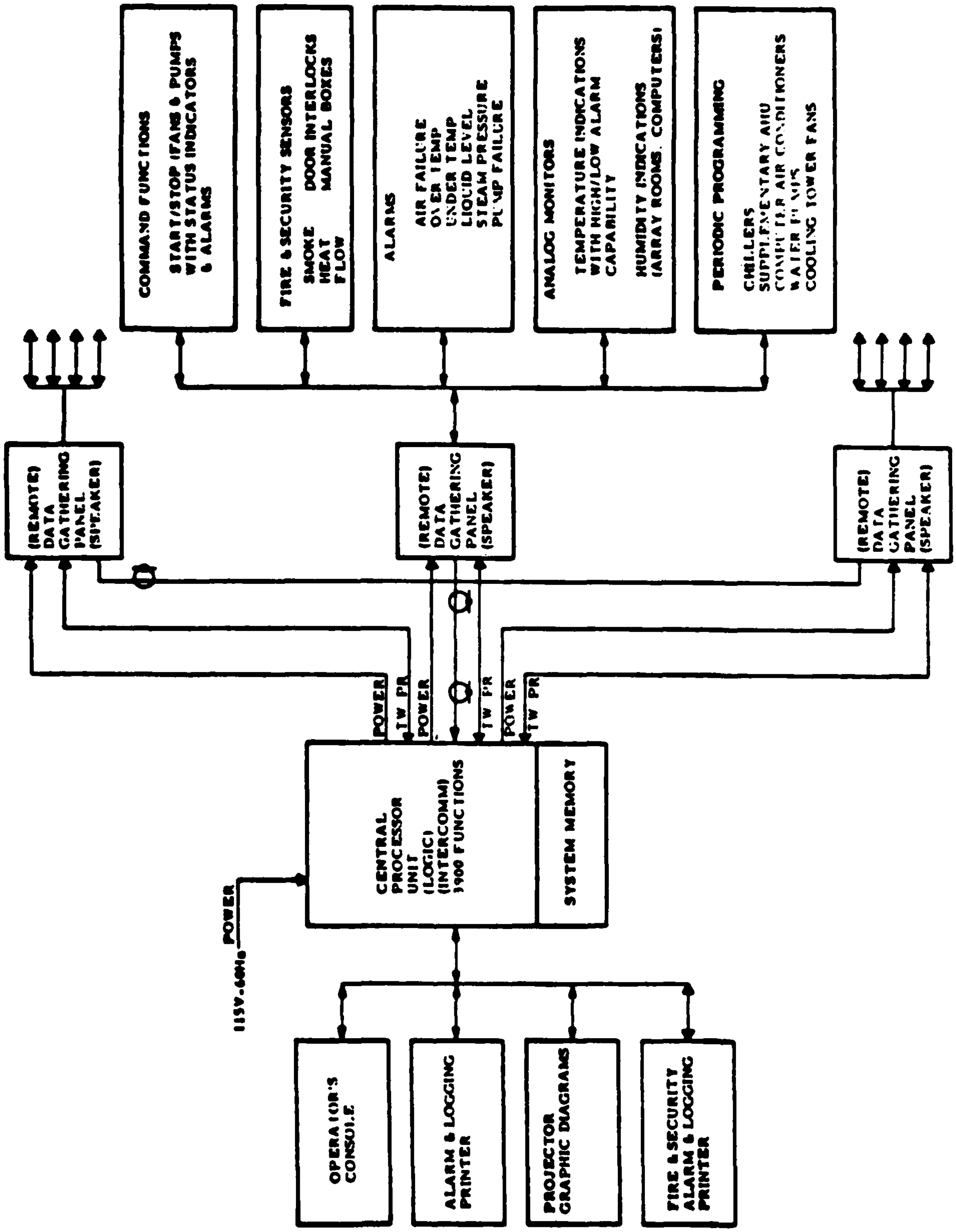

Figure 5.1.4-1. PAVE PAWS FMS DELTA 2000 SYSTEM BLOCK DIAGRAM

Table 5.1.4-1. PAVE PAWS - DELTA 2000 POINT DIRECTORY

POINT NO.	CAGE CARD	FUNCTION	POINT IPD	DGP
1.01.01	1F1	FIRE ALARM ZONE 1A	SVN/FN	1A
1.01.02	1F1	FIRE ALARM ZONE S1	SVN/FN	
1.01.03	1F1	FIRE ALARM ZONE S2	SVN/FN	
1.01.04	1F1	FIRE ALARM ZONE S3	SVN/FN	
1.01.05	1F1	FIRE ALARM ZONE 2	SVN/FN	
1.01.06	1F1	FIRE ALARM ZONE A	SVN/FN	
1.01.07	1F1	FIRE ALARM ZONE 1	SVN/FN	
1.01.08	1F1	FIRE ALARM ZONE 4	SVN/FN	
1.01.09	1F1	FIRE ALARM ZONE 1B	SVN/FN	
1.01.10	1F1	FIRE ALARM ZONE 3	SVN/FN	
1.02.01	1F1	FIRE ALARM ZONE 2A	SVN/FN	2A
1.02.02	1F1	FIRE ALARM ZONE 2B	SVN/FN	
1.02.03	1F1	FIRE ALARM ZONE 7	SVN/FN	
1.02.04	1F1	FIRE ALARM ZONE 8	SVN/FN	
1.03.01	1F1	FIRE ALARM ZONE 3A	SVN/FN	3A
1.03.02	1F1	FIRE ALARM ZONE 3B	SVN/FN	
1.03.03	1F1	FIRE ALARM ZONE 10	SVN/FN	
1.03.04	1F1	FIRE ALARM ZONE 11	SVN/FN	
1.03.05	1F1	FIRE ALARM ZONE 9	SVN/FN	
1.04.01	1F1	FIRE ALARM ZONE 4A	SVN/FN	4A
1.04.02	1F1	FIRE ALARM ZONE 4B	SVN/FN	
1.04.03	1F1	FIRE ALARM ZONE 12	SVN/FN	
1.04.04	1F1	FIRE ALARM ZONE 13	SVN/FN	
1.04.05	1F1	FIRE ALARM ZONE 6	SVN/FN	
1.05.01	1F1	FIRE ALARM ZONE 5A	SVN/FN	5A
1.05.02	1F1	FIRE ALARM ZONE 5B	SVN/FN	
1.05.03	1F1	FIRE ALARM ZONE 14	SVN/FN	
1.05.04	1F1	FIRE ALARM ZONE 5	SVN/FN	
1.05.05	1F1	CORE SYSTEM DUCT DETECTOR	SVN/FN	
1.05.06	1F1	ARRAY SYSTEM DUCT DETECTOR	SVN/FN	
1.06.01	1S1	EIP ENABLE CARD (UTILITY BUILDING)	OFF	6A
1.06.02	1F1	FIRE ALARM ZONE 15	SVN/FN	
1.06.03	1F1	LIMIT SWITCH ZONE A	SVN	
1.07.01	1F1	EMERGENCY EXIT - NOSE DOOR MONITOR	INN-INA	1A
1.07.03	1F1	RECEIVING DOCK DOOR MONITOR	SCC/ACC AL-INA/N-INN	

Table 5.1.4-1. PAVE PAWS - DELTA 2000 POINT DIRECTORY (Continued)

POINT NO.	CAGE CARD	FUNCTION	POINT IPD	DGP
1.08.01	1F1	ROOF HATCH DOOR MONITOR	INN-INA	5
1.09.01	1D3	SF-1, RF-1 START/STOP	ON-OFF	5A
1.09.02	2V2a	SF-1, RF-1 RUN TIME	HRS	
1.09.03	2V2b	SF-1, RF-1 RUN TIME	HRS	
1.09.04	1D2	CORE PURGE COMMAND	ON-OFF	
1.09.05	1C1	SF-1 LOW TEMP ALARM (FREEZE STAT)	NML-ALM	
1.09.06	1A1	SF-1 SUPPLY AIR TEMP	DEG	
1.09.07	2V2a	SP-1 RUN TIME	HRS	
1.09.08	2V2b	SP-1 RUN TIME	HRS	
1.09.09	2C9a	SP-1 STATUS	NML-ALM	
1.09.10	2C9b	SP-1 HOT WATER RETURN TEMP ALARM	NML-ALM	
1.10.01	1D3	SF-2 START/STOP	ON-OFF	5B
1.10.02	2V2a	SF-2 RUN TIME	HRS	
1.10.03	2V2b	SF-2 RUN TIME	HRS	
1.10.04	1D3	SF-3 START/STOP	ON-OFF	
1.10.05	2V2a	SF-3 RUN TIME	HRS	
1.10.06	2V2b	SF-3 RUN TIME	HRS	
1.10.07	2V2a	EF-1 RUN TIME	HRS	
1.10.08	2V2b	EF-1 RUN TIME	HRS	
1.10.09	1D2	ARRAY PURGE COMMAND	ON-OFF	
1.10.10	2C9a	EF-1 STATUS	ON-OFF	
1.10.11	2C9b	ARRAY SYSTEM LOW TEMP ALARM	NML-ALM	
1.10.12	1A1	ARRAY SYSTEM SUPPLY AIR TEMP	DEG	
1.11.01	2C9a	ARRAY FACE A 1st FLOOR HIGH TEMP ALARM	NML-ALM	1A
1.11.02	2C9b	ARRAY FACE A PLATFORM 1A HIGH TEMP ALARM	NML-ALM	
1.11.03	2C9a	ARRAY FACE B 1st FLOOR HIGH TEMP ALARM	NML-ALM	
1.11.04	2C9b	ARRAY FACE B PLATFORM 1B HIGH TEMP ALARM	NML-ALM	
1.12.01	2C9a	ARRAY FACE A 2nd FLOOR HIGH TEMP ALARM	NML-ALM	2A
1.12.02	2C9b	ARRAY FACE A PLATFORM 2A HIGH TEMP ALARM	NML-ALM	
1.12.03	3C1a	ARRAY FACE B 2nd FLOOR HIGH TEMP ALARM	NML-ALM	
1.12.04	3C1b	ARRAY FACE B PLATFORM 2B HIGH TEMP ALARM	NML-ALM	
1.12.05	3C1c	CO_2 RELAY STATUS KITCHEN AREA	NML-ALM	
1.12.06	2V2a	EXHAUST FAN RUN TIME TOTAL	HRS	
1.12.07	2V2b			
1.13.01	2C9a	ARRAY FACE A 3rd FLOOR HIGH TEMP ALARM	NML-ALM	3A
1.13.02	2C9b	ARRAY FACE A PLATFORM 3A HIGH TEMP ALARM	NML-ALM	
1.13.03	3C1a	ARRAY FACE B 3rd FLOOR HIGH TEMP ALARM	NML-ALM	
1.13.04	3C1b	ARRAY FACE B PLATFORM 3B HIGH TEMP ALARM	NML-ALM	
1.13.05	3C1c	ROOM 313 HIGH TEMP ALARM	NML-ALM	
1.13.06	1A1	ROOM 305 TEMP READOUT	DEG	
1.13.07	1B1	ROOM 305 HUMIDITY READOUT	RH	
1.13.08	2C9	UPS #1	NML-ALM	
1.13.09	2C9	UPS #2	NML-ALM	

Table 5.1.4-1. PAVE PAWS - DELTA 2000 POINT DIRECTORY (Continued)

POINT NO.	CAGE CARD	FUNCTION	POINT IPD	DGP
1.14.01	3C1a	ARRAY FACE A 4th FLOOR HIGH TEMP ALARM	NML-ALM	4A
1.14.02	3C1b	ARRAY FACE A PLATFORM 4A HIGH TEMP ALARM	NML-ALM	
1.14.03	3C1c	ARRAY FACE B 4th FLOOR HIGH TEMP ALARM	NML-ALM	
1.14.04	3C1a	ARRAY FACE B PLATFORM 4B HIGH TEMP ALARM	NML-ALM	
1.14.05	3C1b	ROOM 402 HIGH TEMP ALARM	NML-ALM	
1.14.06	3C1c	ROOM 405 HIGH TEMP ALARM	NML-ALM	
1.14.07	1C1	ROOM 413	NML-ALM	
1.15.01	2C9a	5th FLOOR FACE A COMPT	NML-ALM	5B
1.15.02	2C9b	PLATFORM 5A FACE B COMPT	NML-ALM	
1.15.03	2C9a	5th FLOOR FACE B COMPT	NML-ALM	
1.15.04	2C9b	PLATFORM 5A FACE A COMPT	NML-ALM	
1.16.01	2A9a	HWS TEMP FROM UTILITY BUILDING	DEG	1B
1.16.02	2A9b	COOL TOWER RETURN TEMP	DEG	
1.16.03	2A9a	CHWS TEMP	DEG	
1.16.04	2A9b	ECWS TEMP	DEG	
1.16.05	1D3	CHWP-1 STARTER	ON-OFF	
1.16.06	2V2a }	CHWP-1 RUN TIME	HRS	
1.16.07	2V2b }			
1.16.08	1D3	TWP-1 STARTER	ON-OFF	
1.16.09	2V2a }	TWP-1 RUN TIME	HRS	
1.16.10	2V2b }			
1.16.11	1D3	LC-1 CONTROL PANEL INTERLOCK	ON-OFF	
1.16.12	2V2a }	LC-1 RUN TIME	HRS	
1.16.13	2V2b }			
1.16.14	1D3	LC-2 CONTROL PANEL INTERLOCK	ON-OFF	
1.16.15	2V2a }	LC-2 RUN TIME	HRS	
1.16.16	2V2b }			
1.16.17	1D3	CHWP-2 STARTER	ON-OFF	
1.16.18	2V2a }	CHWP-2 RUN TIME	HRS	
1.16.19	2V2b }			
1.16.20	1D3	TWP-2 STARTER	ON-OFF	
1.16.21	2V2a }	TWP-2 RUN TIME	HRS	
1.16.22	2V2b }			
1.16.23	1D3	ECWP-1 STARTER	ON-OFF	
1.16.24	2V2a }	ECWP-1 RUN TIME	HRS	
1.16.25	2V2b }			
1.16.26	1D3	ECWP-2 STARTER	ON-OFF	
1.16.27	2V2a }	ECWP-2 RUN TIME	HRS	
1.16.28	2V2b }			
1.16.29	1D2	COOL TOWER-1 SUPPLY VALVE	OP-CL	
1.16.30	1D2	COOL TOWER-2 SUPPLY VALVE	OP-CL	
1.16.31	1D2	CTF-1 CTF-2 START SEQUENCE CHANGE	ON-OFF	
1.16.32	1C1	FILTER ALARM FOR ECWP's	NML-ALM	

Table 5.1.4-1. PAVE PAWS - DELTA 2000 POINT DIRECTORY (Continued)

POINT NO.	CAGE CARD	FUNCTION	POINT IPD	DGP
1.17.01	2V2a	CTF-1 TOTALIZER	HRS	1C
1.17.02	2V2b			
1.17.03	2V2a	CTF-2 TOTALIZER	HRS	
1.17.04	2V2b			
1.17.05	2S9a	CTF-1 STATUS	ON-OFF	
1.17.06	2S9b	CTF-2 STATUS	ON-OFF	
1.18.01	1D6	XFMR A SEQUENCER INHIBIT	OP-CL	1C
1.18.02	1D6	XFMR B SEQUENCER INHIBIT	OP-CL	
1.18.03	3C1a	XFMR A WINDING TEMP ALARM	NML-ALM	
1.18.04	3C1b	XFMR A SECONDARY CIRCUIT BREAKER	NML-ALM	
1.18.05	3C1c	XFMR A CONTROL POWER XFMR	NML-ALM	
1.18.06	3C1a	XFMR B WINDING TEMP ALARM	NML-ALM	
1.18.07	3C1b	XFMR B SECONDARY CIRCUIT BREAKER	NML-ALM	
1.18.08	3C1c	XFMR B CONTROL POWER XFMR	NML-ALM	
1.18.09	2C9a	BUS TIE CIRCUIT BREAKER ALARM	NML-ALM	
1.18.10	2C9b	UNDER VOLTAGE SIGNAL NORMAL CONTACTOR	NML-ALM	
1.18.11	2C9a	MCC 2A STATUS	NML-ALM	
1.18.12	2C9b	MCC 2B STATUS	NML-ALM	
1.18.13	3C1a	DP-1 STATUS	NML-ALM	
1.18.14	3C1b	DP-2 STATUS	NML-ALM	
1.18.15	3C1c	DP-3 STATUS	NML-ALM	
1.18.16	3C1a	DP-4 STATUS	NML-ALM	
1.18.17	3C1b	DP-9 STATUS	NML-ALM	
1.18.18	3C1c	FIRE PUMP STATUS	NML-ALM	
1.18.19	3C1a	DP-5	NML-ALM	
1.18.20	3C1b	DP-6	NML-ALM	
1.18.21	3C1c	DP-7	NML-ALM	
1.18.22	3C1A	DP-8	NML-ALM	
1.18.23	3C1b	FUTURE	NML-ALM	
1.18.24	3C1c	FUTURE	NML-ALM	
1.19.01	1D3	SU-1 STARTER	ON-OFF	3A
1.19.02	2V2a	SU-1 RUN TIME	HRS	
1.19.03	2V2b			
1.19.04	1D3	SU-2 STARTER	ON-OFF	
1.19.05	2V2a	SU-2 RUN TIME	HRS	
1.19.06	2V2b			
1.19.07	1D3	SU-3 STARTER	ON-OFF	
1.19.08	2V2a	SU-3 RUN TIME	HRS	
1.19.09	2V2b			
1.19.10	1D3	SU-4 STARTER	ON-OFF	
1.19.11	2V2a	SU-4 RUN TIME	HRS	
1.19.12	2V2b			

Table 5.1.4-1. PAVE PAWS - DELTA 2000 POINT DIRECTORY (Continued)

POINT NO.	CAGE CARD	FUNCTION	POINT IPD	DGP
1.20.01	1D3	SU-5 STARTER	ON-OFF	4A
1.20.02	2V2a	SU-5 RUN TIME	HRS	
1.20.03	2V2b			
1.20.04	1D3	SU-6 STARTER	ON-OFF	
1.20.05	2V2a	SU-6 RUN TIME	HRS	
1.20.06	2V2b			
1.20.07	1D1	FIRE SIGNAL FROM DGP-6A DEVICES	FN-FA	
1.21.01	1F1	FA ZONE 1 SLBM (POWER PLANT)	SVN/FN	7A
1.21.02	1F1	FA ZONE 2 SLBM	SVN/FN	
1.21.03	1F1	FA ZONE 3 SLBM	SVN/FN	
1.21.04	1F1	FA ZONE 4 SLBM	SVN/FN	
1.22.01	1D3	HWP-1 STARTER (UTILITY BUILDING)	ON-OFF	6A
1.22.02	2V2a	HWP-1 RUN TIME	HRS	
1.22.03	2V2b			
1.22.04	1D3	HWP-2 STARTER	ON-OFF	
1.22.05	2V2a	HWP-2 RUN TIME	HRS	
1.22.06	2V2b			
1.22.07	1A1	OUTDOOR AIR SENSOR READOUT	DEG	
1.22.08	1B1	OUTDOOR HUMIDITY READOUT	RH	
1.22.09	1U1	BAROMETER PRESSURE READOUT	IN	
1.22.10	2C9a	CT-1 SUMP LO TEMP ALARM	NML-ALM	
1.22.11	2C9b	CT-2 SUMP LO TEMP ALARM	NML-ALM	
1.22.12	3C1a	BOILER-1 FLAME FAILURE	NML-ALM	
1.22.13	3C1b	BOILER-2 FLAME FAILURE	NML-ALM	
1.22.14	3C1c	ELECTRIC EMERGENCY FIRE PUMP OPERATION	NML-ALM	
1.22.15	3C1a	BASE WATER LOW LIMIT	NML-ALM	
1.22.16	3C1b	FIRE WATER LINE LOW PRESSURE	NML-ALM	
1.22.17	3C1c	DIESEL FIRE PUMP TROUBLE	NML-ALM	
1.22.18	3C1a	DIESEL GENERATOR EMERGENCY CONTACTOR	NML-ALM	
1.22.19	3C1b	FIRE ROOM LOW TEMP ALARM	NML-ALM	
1.22.20	3C1c	ELECTRIC FIRE PUMP POWER FAILURE	NML-ALM	
1.22.21	2C9a	DIESEL GENERATOR MAIN CIRCUIT BREAKER	NML-ALM	
1.22.22	2C9b	LOAD BANK CIRCUIT BREAKER.	NML-ALM	
1.22.23	2C9a	DIESEL GENERATOR TROUBLE SIGNAL (GEN)	NML-ALM	
1.22.24	2C9b	DAY TANK LOW LEVEL ALARM	NML-ALM	
1.22.25	1C1	FIRE DIESEL GENERATOR RUN ALARM	NML-ALM	
1.23.01	2V2a	DWBP-1 RUN TIME	HRS	1C
1.23.02	2V2b			
1.23.03	2V2a	DWBP-2 RUN TIME	HRS	
1.23.04	2V2b			
1.23.05	2V2a	DWBP-3 RUN TIME	HRS	
1.23.06	2V2b			
1.23.07	2C9a	LOW AIR PRESSURE ALARM	NML-ALM	
1.23.08	2C9b	STEAM GENERATOR PRESSURE SWITCH	NML-ALM	
1.23.09	1C1	DWP LOW PRESSURE	NML-ALM	
1.23.10	2S9a	DMTS SF STATUS COOLER	ON-OFF	
1.23.11	2S9b	SSMTS SF STATUS COOLER	ON-OFF	

long list has been kept in the body of the text, rather than in the appendix, because it illustrates the current functions of the FMS, an understanding of which is essential to evaluate our proposed recommendations.

5.1.4.1 Ancillary Facility Monitoring

Unlike the other sensors at the site which are tied into the FMS, the Cooling Environmental Monitor (CEM) and external humidity, temperature, barometric pressure, dew point, and chilled water flow readings are tied into the main computer and can be read on the RCL (Radar Controller) displays. Internal dew point is recorded on a chart in the computer room. The individual CYBER main computer cabinets have over-temperature alarms and switches to shut down the individual un[illegible] when the temperature goes out of tolerance. Otis reports that the Datalok 10 hardware for chilled water flow measurement monitoring is not supported in the technical data.

5.1.4.2 Computer Room Temperature & Humidity Tolerances

The AN/FYK013 Cyber computers require temperature and humidity be maintained at 72^{o}F and 50%. Alarms are set for 85^{o}F and 54%. One minute after reaching 56%, or upon reaching 93^{o}F, the Cybers shut down. The circuit breakers are set to drop out at 100% humidity.

5.1.4.3 Comments from Otis on their FMS

FMS is great as a system monitor, but not as a controller. Consequently, switching to back-up/redundant systems is done manually in most cases, rather than under FMS Control. Honeywell documentation is inadequate. (Otis received more documentation during visit.) The T.O.s (Technical Orders) are too general. Problems exist with interfaces, however, very few problems have occured with sensors. There is no data retained in memory in the FMS. If simultaneous multiple failures occur, only one item prints out. It skips multiple alarms, (meaning that a queuing problems exists). It locks up on one problem, printing it out until the problem is fixed. Pneumatic environmental controls are inadequately supported in the technical data and their operation sequence is wrong. FMS schematics don't match the installed hardware. (Witnessed several red-lined drawings.)

The FMS schedules the operation of the ventilation fans. Frequently, the scheduled switchover from one fan to another doesn't occur as it should. This could cause the equipment in the affected spaces to shut down when the resultant temperature rise causes the local over-temperature protection circuitry to cut power to the units. However, the FMS reports the out-of-tolerance temperature condition so that it can be corrected manually before the shutdown occurs, if the MMCO catches the message on the FMS. When there is a lot of activity in the TOR (Tactical Operations Room) the MMCO could be easily pre-occupied, causing the message to be ignored for several critical minutes.

Additional problems cited by Otis personnel on their FMS is that the time indication jumps giving faulty calendar and clock records and readouts. Also, no back-up exists for the printout device or for the CPU.

5.1.5 COMMERCIAL POWER

A lack of adequate instrumentation prevents the PAVE PAWS sites from identifying commercial power transients or distingushing between interruptions and spikes. The site is forced to call and ask the local power company what their records show when such phenomena are suspected.

While an attempt is being made to improve the quality of the commercial power at Otis, it will be difficult to quantify the improvement without adequate instrumentation and recording devices.

Power bumps are sometimes preceded by ripples. A power monitor could trigger an alarm to shift from commerical power to avoid the loss of the site.

Beale CE (Civil Engineering) is considering hanging capacitors across the high voltage lines to smooth out transients.

Erratic performance of the FMS has been attributed to problems with the commercial power. Such behavior could create safety problems.

An investigation of the potential consequences of erratic FMS behavior should be undertaken and appropriate measures introduced to ensure that all potential personnel and equipment hazards are eliminated.

5.1.6 UPS (Uninterruptable Power Supplies)

Model Number:

208-625T/P3-120/208 EXIDE 101 710 233/RL 76394/97.

The two UPS at each PAVE PAWS site support the equipment diagrammed in Figure 5.1.6-1. If UPS #1 goes down, the designated critical 60 Hz loads are transferred automatically to UPS #2. When UPS #2 goes down, if UPS #1 is available, the transfer must be done manually.

The UPS input rating is 185 amps at 208 volts. DC link rating is 416 amps at 135 volts and AC output is rated at 174 amps 120/208 volts.

The sites report that they seldom lose both UPS. When one UPS is down, however, half the site's data processing capability is lost, although the remaining half can support system operation. The UPS provides 5 to 6 minutes of backup to preserve data and permit orderly ADP (Automatic Data Processing) shutdown. Since the UPS does not power the radar, both missions go RED when the UPS becomes the source of power.

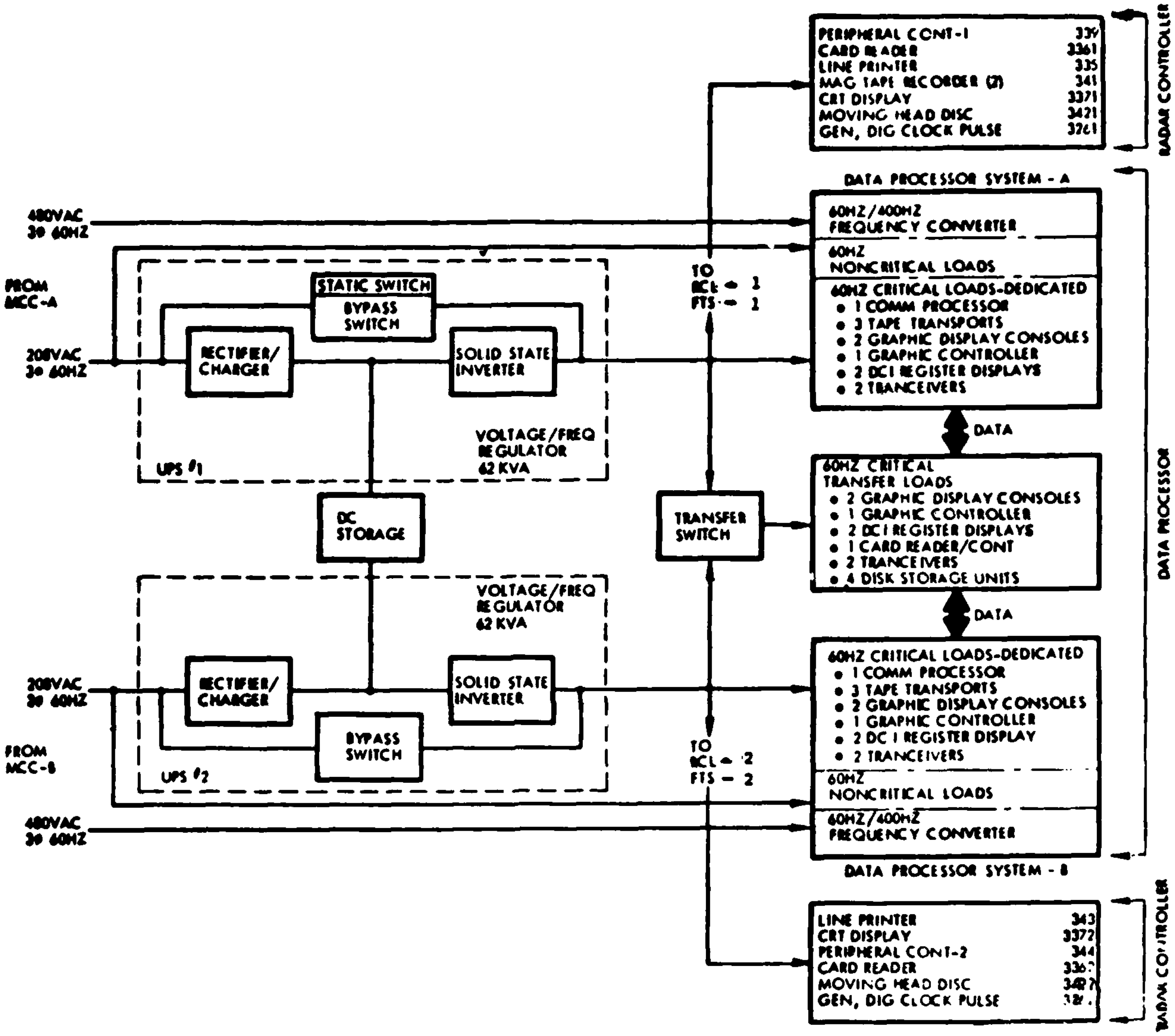

Figure 5.1.6-1. PAVE PAWS UNINTERRUPTIBLE POWER SOURCE AND LOADS

Fuses have blown in the UPS on numerous occasions for no apparent reason. Replacement of the blown fuses (400 amp on converter leg input) without any other corrective action has usually gotten the UPS back on line. It could be that the fluctuating load of the radar transmitter accelerates fatigue of the fuse until it fails mechanically, rather than due to the current demand exceeding the fuse rating. Another possibility is that high frequency current transients caused by the fluctuating transmitter load put enough energy into the fuse link that it fails despite the 60 Hz RMS current appearing to stay within tolerance. Whatever the cause, it will probably remain a mystery unless better instrumentation is employed to diagnose the failures. It is suggested that fuses that fail in this manner be examined by the Air Force Materiel Lab for manufacturing defects and other failure causes.

The System 17 computers which run the displays in the TOR are very sensitive to power glitches. If the power conditioning of the UPS is lost, under certain circumstances, the displays go down and the System 17's must be booted-up again using the card reader. The site goes RED for several minutes when this happens while the UPS and System 17's are being brought back up.

We were told that the power conditioning feature of the UPS was not specified in the prime system contract and would not be necessary had adequately conditioned commercial and diesel power been provided GFE. The Air Force specified that the prime hardware operate on Mil-E-4158 GFE power. To the extent that the commercial and diesel generator power

meets this specification, the power conditioning feature of the UPS is implied, since the prime hardware cannot operate without it. Several proposals exist to improve the situation as discussed in the commercial power and diesel generators sections, including adding a third UPS as a backup. Each of these proposals require additional funds from the Air Force to implement. (A third UPS would cost about $160K for each site.) Our recommendation discussed in the next section, to further split the power, may be an exception. Until fixed, the UPS situation will continue to be a contributor to PAVE PAWS RED and AMBER Outages.

One recent improvement by PAVE PAWS was to add alarms to the FMS to report when the UPS goes on static bypass or crashes. As originally installed, the logic circuitry of UPS #2 would go down whenever UPS #1 went down. A change to correct this situation was planned by Beale for installation shortly after our visit.

The problem of modern military systems failure to operate on available unconditioned power is reported in the literature for all services. The 465 L SACCS was reported to require the power conditioning feature of its UPS in order to operate. Apparently the Cybers and the System 17 Display Controllers at PAVE PAWS have the same dependency.

The 33rd Communications Group at March reported that there are no generators on base that will operate computers without the power conditioning of an UPS.

5.1.7 THUMP MODE

The PAVE PAWS transmitters of the phased array radar are fired in bursts that cause the current to fluctuate furiously. These fluctuations cause the needle of the power meter to change the reading by a factor of two, as fast as (it appears) the mechanism can respond. Because of the damping of this mechanical device, it is unlikely that the needle can keep up with the fluctuations. This means that the true peaks could easily exceed the indication. The instantaneous rate-of-change: $\frac{dP}{dt}$, cannot be quantified from such a crude device. The site uses about 1000KW without firing the transmitters. Excursions beyond 2000KW are indicated by the power plant panel meters in the control room when the radar is transmitting. The true peak magnitude remains unknown. Symptoms associated with the thump mode are:

- The lights flicker
- The fuel racks on the diesels oscillate wildly (injector fuel output is governed by rack travel)
- The motor generators vibrate, apparently wearing out their couplings at accelerated rates

Vapor-type lights, such as those used in the power plant machinery space, are most sensitive to the load fluctuations, making it difficult to work for very long in their strobe-like illumination. The sites have reported that some measures, such as splitting the bus to isolate the radar power from the more sensitive loads have diminished the problem to some extent; however, it remains marginally bearable. The wild fluctuations of the diesel generator fuel racks will

likely result in early wearout. Replacement parts for these old machines could become scarce.

Various sources indicated that the radar controller software has been modified to smooth-out the sequence and pattern in which transmitters fire, giving a more uniform load. No data was available at the sites to quantify any improvement; however, a slight qualitative improvement was believed to be the result. Beale reported that the governors on their diesels had recently been set to smooth light flicker.

Our systems engineering analysis of the PAVE PAWS "Thump Mode" problem led to a new recommendation: to save the funds required to place the Otis site on a different commercial power source (estimated at over $1M) by splitting the power in a different way---specifically to operate the computers and other delicate loads on diesel generated power at all times and to operate the radar on commercial power except during alerts and brownouts. Separate diesel generators would be used for the radar such that the radar noise could never get conducted back through the power mains to the delicate loads. This would relax the dependancy on the UPS and negate the need for a third unit at each site.

5.1.8 EXISTING CONDITION MONITORING

Both PAVE PAWS sites rely on periodic oil sample analysis and trending to determine when to change oil and filters. Some crude determination of carbon and metal particle content is done locally. Samples

are sent from both sites to CEMIRT at Colorado Springs (Peterson AFB) once a month under the SOAP (Spectroscopic Oil Analysis Program) Tri-Service Program, to determine the condition of the engine and the condition of the oil. Unfortunately, CEMIRT no longer reports viscosity of the oil. Apparently SAC regs have not caught up with oil analysis/trend data to the satisfaction of at least one (Otis) power plant operator who favors ADCOM REG 91-1 (which no longer applies since PAVE PAWS transitioned over to SAC).

When viscosity rises by 5% due to fuel dilution or increases by 14 ppm water, the power plant maintenance personnel feel the oil should be changed (max 34 ppm water tolerated before change). The sites should be provided a viscosity meter.

The very limited capability for monitoring power is discussed under power plant instrumentation. Consideration should be given to including the chiller oil in the soap program if not already covered.

5.1.9 POWER PLANT INSTRUMENTATION

Otis reported that only about one-third of the three year old meters in the control room work. Faulty engine instrumentation represents the bulk of the problem. The electrical meters appear to have held up. The control room meters are used as remote indicators. Recorded readings are taken manually from the engine panel meters out on the floor which are kept more accurate through periodic calibration. None of the alarms can be heard outside the control room. There are

none out in the plant. There are no charts for commercial power. At minimum, voltage and frequency recording meters should be installed with alarms connected to the FMS.

Beale has a Power Line Disturbance Analyser, Dranetz Model 606-L, which alarms and prints out power glitches. Unfortunately, at the time of the visit, the unit was installed across the 480 volt utility load instead of across the 2400 volt technical load.

We discovered that AFCC Headquarters has 3 Dranetz meters with extended capability which they lend out to bases to diagnose power glitch problems. AFCC/DEO at Scott AFB is studying the power quality problem for communications and computers. At that time, one of their Dranetz meters was in Iceland, another at Castle AFB and the 3rd at Scott waiting parts. SCD/LGPW was informed of the existence and availability of these meters at AFCC/DEO. We anticipate these meters will provide the Otis PAVE PAWS site the means to characterize the quality of commercial power presently available to them, and to evaluate the comparative quality of alternate sources. It is further hoped that use of these devices will define the quality of the power generated at the site. (We learned later that the local Dranetz representatives may also be able to lend the sites meters for evaluation).

5.1.10 EMP FILTERS

There are electromagnetic pulse filters installed at the sites on the commercial power line and the diesel generator sets. There are three large EMP filters for the commercial power input line, one on each phase wire. There are 18 EMP filters for the six diesel generator sets, one on each phase wire for each generator set.

Mr. Howard M. Fowles of Mission Research Corporation, Alburquerque, New Mexico, was at the Beale site during our visit conducting and EMP filter investigation for the Air Force Weapons Laboratory (AFWF/NTYC). RADC/RBES later provided three Mission Research EMP hardness reports obtained from AFWL.

5.1.11 Power Switch Gear

The switch gear is reported as a nuisance to troubleshoot because the prints do not match the hardware. The drawings are up to Revison F and reportedly still bad. Problems with breakers were also reported. When a radiator motor failed at Otis, the feeder breaker did not isolate the fault. This caused the main breaker to open, resulting in loss of the bus, which shut down the site.

5.1.12 RCLs (Radar Controllers) AN/OK399

Modcomp IV/25s have been used for the two RCL main frames at each site. The RCLs have two main functions: tactical and maintenance, but they also act as a monitor for several critical sensors not covered by the FMS (cf 5.1.4). To be truly redundant, a third RCL is required, since it is impossible to perform off-line diagnostics when one RCL is down. Conversely, it is not now possible to operate the radar while troubleshooting the system with one RCL out of commission. The loss of one UPS also makes it impossible to use the off-line RCL for troubleshooting or training; however, it does not eliminate the standby RCL's usefulness as a back-up to the RCL on line. It should also be resolved whether the back-up RCL at one site could troubleshoot the other site over data lines or satellite data link, eliminating the need for the 3rd RCL.

5.1.13 GPSPs (General Purpose Signal Processors)

The site interviews revealed the vulnerability to "soft kills" outlined in this and the following sections. PAVE PAWS sites have four GPSPs. Three are required, the fourth is a back-up. There are about 20 cards in the GPSPs that cannot be removed without "taking-out" the other GPSPs. These cards can be removed without disrupting the other GPSPs provided the power to that GPSP is removed prior to changing the cards. It is recommended that adequate warning

be made visible on the equipment access and in the tech data to ensure proper procedure is followed in removing these cards.

Single paths in the array group drivers are also reported to cause loss of one whole radar array face when the circulator for that face is lost. Because the field view of the two radar faces intersect, the loss of one face would constitute a reduction in coverage of less than 50%. Lack of exciter redundancy is also described as becoming a problem when one exciter is lost.

5.1.14 POWER TRANSISTORS

From one to three power transistors per day fail in the radar elements. It takes ten minutes to run an element test. The questions remain: Does the element test interfere with the mission when run in ten minutes? If so, how long does it take to run on a non-interference basis (time shared with the mission)? and, How can soft kills resulting from this situation be eliminated or reduced? (Note that several elements can be lost before the mission is impacted).

5.1.15 FUEL AND LUBE OIL STORAGE AND USAGE

Beale has storage capacity of 160,000 gallons in four 40,000 gallon tanks. This provides about 37 twenty-four hour days operating capability at 60 gallons per hour, per diesel.

Each diesel has its own day tank. 40 weight 2104C Mil Spec oil is used for lubrication. The amount stored versus the utilization rate was not noted, however used oil is stored until picked-up for recycling.

The quality of the fuel and lube oil may become a monitoring issue. The potential need for aereation of stored fuel is an issue identified by CE at the sites.

5.1.16 VENTILLATION FANS

At Otis, the problem first revealed by the maintenance people was that the Wood's English-made precision controllable-pitch fans fly apart. Vibration monitoring employed to predict failure could trigger shut-down before the fan ingests its control rod retainer mechanism, which chews-up the balanced blades and results in costly repairs and downtime.

At Beale, the fans are made by Joy (but marked Alliance). No self-destruct problems were reported with these fixed-pitch units.

5.1.17 TECH DATA

Air Force Regulations 91-4 and 91-8 cover power and ECUs respectively.

The following problems with technical data were identified during the PAVE PAWS site visits:

- The set of manuals and PM is inadequate on power production according to the civil engineering operators.
- Beale reports good data on FMS and Data Acquisition Panels, however Otis reports just the opposite. Apparently different sub-contractors made the installations at the two sites.
- Climet Datalok 10 technical data is reported non-existent by individuals at both sites.
- Commercial manuals tend to contain great quantities of extraneous information on equipment that is not part of the installation, and on installation schemes that have not been used. A great deal of time is lost trying to determine what part of the information actually applies. This problem, found throughout the military, was cited by individuals at both sites.

5.1.18 MMICS (Maintenance Management Information and Control System)

The MMICS data input began at Otis in April 1981. Air Force Pamphlet AFP66-10 MMICS Guide for Maintenance Managers describes the information available from the MMICS data base and explains the transaction identification code (TRIC) used to retrieve that information. Each PAVE PAWS site has four MMICS terminals. The MMCO uses one terminal to input Equipment Status Reports. The MMICS files maintenance NCO and Job Control Supervisor also have terminals. Otis depends on the B3500 computer at Hanscom to host their MMICS files and are often bumped for days at a time by higher priority jobs, such as civilian

payroll. Recently 400 Hertz noise on the commercial phone lines prevented passing MMICS data between Otis and Hanscom creating a substantial backlog. The accumulated backlog at both sites was alleged to cause the delays in receiving the requested ESR data discussed below.

5.1.19 POWER/FACILITY RELATED DOWNTIME RECORDS

A request for ESR data was made of the MMICS file maintenance NCO at each site to include all P, N, and U downtime coded RED and AMBER outages against the following codes:

MMICS

Equipment ID Nos	Nomenclature	Equipment
REA01	AN/FPS115	RADAR
REB01	AN/OK339	RCL(1)
RE002	AN/OK339	RCL(2)
RE816	AN/FYK013	CYBER(A)
RE819	AN/FYK013	CYBER(B)

NOTE: P, N, and U stand for power, environment and unknown respectively.

Mission Correllation

Codes		Mission
MWN OYOO	ZMSLWARN	Missile Warning
DTL OYOO	ZDATALIN	Dataline

No data has been received from either site despite several attempts over the months since our original request. Apparently the backlog of data to be input into the MMICS prevented extracting the desired data. The following specific outage dates were provided by SAC/SXOG.

<u>POWER/FACILITY RELATED DOWNTIME</u> (RED OUTAGES EXCEPT AS NOTED)
<u>(provided by SAC/SXOG)</u>

OTIS	duration (minutes)	
2/5/81	23	
3/24	91	RED plus 18 minutes AMBER to get consoles up
5/25	96	
5/26	25	
6/20	7	
7/5	108	
8/5	54	(15 power plus 39 environment per Beale)
8/10	44	(Beale data says 2 hrs 44 min!)
8/25	27	
9/7	6	Environment (per Beale)
9/8	9	Power, (per Beale)

BEALE		
2/23/81	96	
3/5	44	
3/26	5	
3/30	25	
4/7	110	
4/10	64	
7/6	97	
7/14	22	
9/17	872	personnel error-safety board installation (per Beale)
9/21	29	(0.06 personnel error)

SXOG indicated that most of the power problems above were probably related to UPS.

In February 1982, the sites were reported to be incapable of extracting the promised data from their respective MMICS files by HQ-SCD/-LGPW. The ESR data available from the computer at Offutt was received 3/4/82. A copy of the printout is included in appendix B.

A lack of correllation exists between this data and the previous list provided by SAC/SXOG (and confirmed by Beale). The conclusion of this analyst is that the MMICS software and data input schemes suffer similar deficiencies to the MDCS. The software of both systems lack the checks and balances that are needed to maintain the quality data base envisioned by the users. For example, when failure reports, parts orders, status reports, etc. are input to the computer, the part name, number, nomenclature, how failed code, work unit code, and other inputs should be compared to a look-up table and discrepancies flagged to ensure that errors are removed. A separate study of all such systems should be made to identify the problem and suggest improvements.

5.1.20 TRAINING

PAVE PAWS

The training for the Honeywell Delta 2000 received by the Com Squadron people at Otis was on different equipment than used at PAVE PAWS, making its utility somewhat questionable. When these people leave, it is likely that the new crew will be trained in the same manner if the AF corporate memory doesn't improve. The Air Force now has an UPS school at Shepherd AFB which hopefully will improve the ability of the attendees to operate, maintain, and troubleshoot their gear.

General

A lack of adequately trained air conditioning mechanics was cited by virtually every Air Force organization visited during this study. One way to ensure that personnel acquire and maintain operation and maintenance skills is to embed the technical manuals in the monitor software along with training exercises. This permits the operator to be guided through the proper steps by responding to a menu and a series of prompts from a terminal. This is accomplished on a smaller scale and for a different purpose when a bank customer uses an automatic teller machine. The menu consists of the options available to the operator. The display prompts the operator to select the appropriate transaction option, enter alpha numeric access codes and dollar amounts through the keyboard, and allows him to verify or correct the input data. When used in conjunction with test and monitoring, as described above, these techniques have become known as organic (or embedded) maintenance and training. Organic maintenance and training should be acquired in conjunction with condition monitoring to realize the full productivity potential available through automation. Full productivity potential here means adequate mission performance and availability, for the least cost of ownership. Life Cycle Performance, a measure of this productivity can be defined as being proportional to output performance and availability and inversely proportional to the cost.

5.2 PAVE PAWS FUTURE SITE CONSIDERATIONS

Lessons learned from the first two sites that should influence future PAVE PAWS and similar site installations are:

1. Increase the responsibility of the prime system contractor for selection, installation, and instrumentation of the power and electronic cooling to ensure compatibility and eliminate several serious interface problems.
2. Substitute Reliability Centered Maintenance for traditional calendar-based practices.
3. Employ condition monitoring where analysis shows it is warranted.
4. Obtain a vibration monitoring baseline for all rotating machinery to form the basis for comparison and trend analysis as the equipment ages, and to ensure misalignment does not create early failures.
5. Resolve how much on-site fuel storage capacity is required and whether aeration or other measures to maintain stored fuel quality should be provided.
6. Ensure that the power plant layout problems of the PAVE PAWS site at Otis are not reproduced. When a leak occurs, a fire breaks out, or some other emergency exists, swift attention is essential. Require plumbing and ancillary equipment not present personnel hazards to plant personnel. Ensure that one can move freely and rapidly among the power units and throughout all machinery spaces and that valves are within reach at floor level.

7. Consider installing a third UPS and retrofitting the first two sites. (Trade off against our power bus splitting recommendation).

8. Require that the chilled water paths on the face of the radar have enough unions between elements to provide for element replacement without unsoldering lines.

9. EMP Filters - Install to avoid moisture penetration experienced at Beale during Periodic Maintenance Open-and-Inspect actions. It has been noted that the filters that lay flat experience more of a problem than those installed upright. (Moisture peneration has been suspected as causing these filters to explode.)

10. FMS - Eliminate queuing problem, provide backup for printer and CPU; add power and cooling sensors and alarms; interface with Modcomp to transfer readings for storage, correlation and trend analysis.

11. Near Field Horns - Consider structural and security improvements in any site upgrades.

12. Use 750 KW diesels vice 1000 KWQ units, to reduce carbon buildup, fuel dilution, and sync problems.

13. Install Emergency Air Cutoff on all PAVE PAWS diesels.

14. Require thorough systems engineering of all changes/improvements.

15. Several observations are made in this report under the general sections that are applicable to PAVE PAWS and vice-versa. Serious consideration should be given to preclude the potential safety hazards identified.

6.0 PAVE PAWS E/M EQUIPMENT DESCRIPTION/FAILURE MODES

For PAVE PAWS to meet its mission demands, it is essential that the electronics of the key subsystems remain operating within their specified temperature environment, as determined by the heat transfer capability of the chilled water system. The air conditioning system must adequately cool the radar, communications equipment, electronic countermeasures gear as well as the attendent personnel. Failure of the air conditioning system can impair the ability of PAVE PAWS to carry out its mission.

Even a mechanically sound air conditioning system that has a minor control problem, or is in need of adjustment, can cause periodic momentary reduction or loss of cooling to vital electronic subsystems, resulting in permanent damage to electronic components.

Parameter/sensor selection and the development of monitoring techniques are prime tasks in the development of the proposed diagnostic system. The fabrication of a reliable electronic system and its packaging may be accomplished by conventional electronic hardware design. The main emphasis is the discussion of the diagnostic method and the sensors for diagnosing the air conditioning and engine-generators. Several valid diagnostic techniques are available and can be implemented to comprise a comprehensive diagnostic system.

Refinement and simplifying of the prototype system would be accomplished through extensive shake-down tests.

6.1 ENVIRONMENTAL CONTROL SYSTEM DESCRIPTION

Figure 6.1-1 displays a typical air conditioning equipment breakdown structure. The three air conditioning subsystems included in this study are: the air conditioning plant, tower water cooling, and chilled water. The PAVE PAWS air conditioning system is made up of a 600-ton prefabricated centrifugal compression refrigeration unit, a thermal purge unit, a prefabricated chilled water unit and a tower water cooling unit. The Centrifugal Refrigeration Machine is a prefabricated unit on a common structural base. It combines the compressor, couplings, drive motor, speed increasers, condenser, cooler (water chiller), controls, safeties and operating support element.

6.1.1 SYSTEM OPERATION

Environmental Control (cooling) is accomplished when heat from the air in the air conditioned spaces is transferred to the chilled water by blowing this air over chilled water cooling coils. (cf Figure 6.1-2) Some equipment is cooled directly by circulating chilled water through the equipment heat sinks, such as the radar elements. The chilled water is delivered to the coils at 42^{O}F and returns at approximately 45^{O}F to the refrigerant-cooled cooler. Here the evaporating refrigerant cools the chilled water to 42^{O}F before it is sent back to the electronics and compartment cooling coils. Tower water cools the condenser where the hot compressed refrigerant vapor is liquified. This condensate is gathered in the condenser float chamber and next passes through the float valve. From there it passes

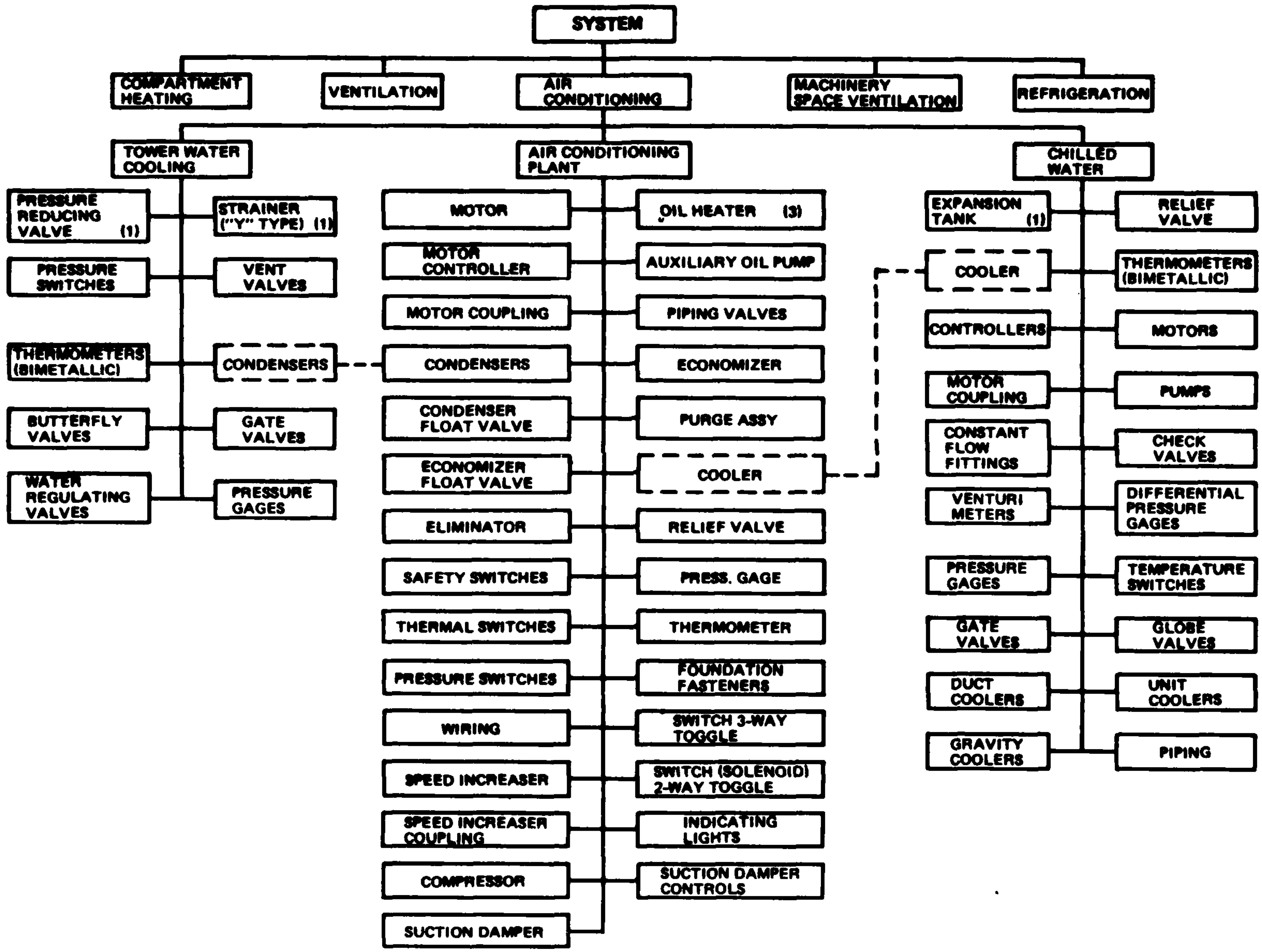

FIGURE 6.1-1. PREFABRICATED CHILLED WATER PLANT AIR CONDITIONING SYSTEM EQUIPMENT BREAKDOWN STRUCTURE.

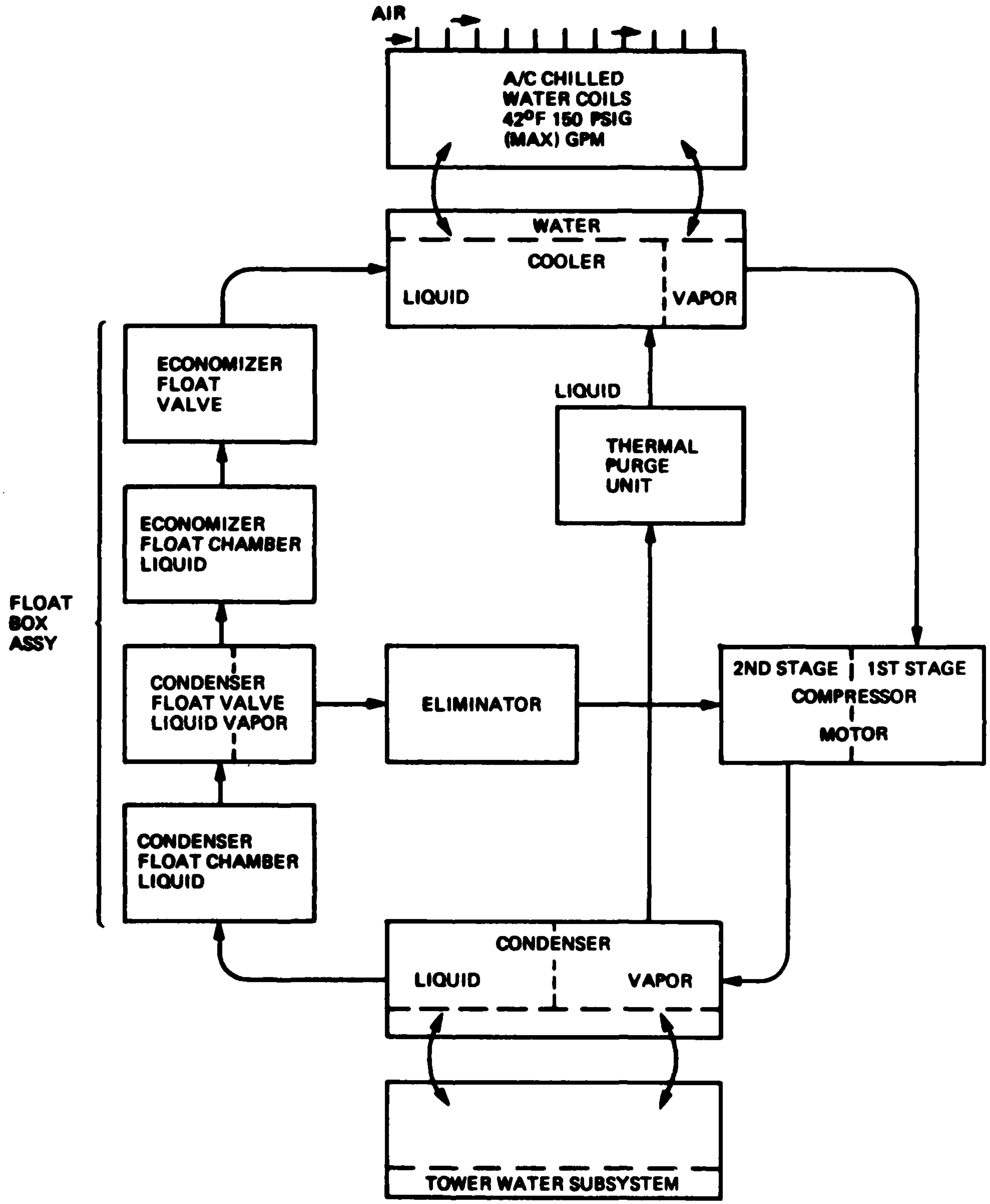

Figure 6.1-2. Functional Diagram of Chilled Water Air Conditioning

to the economizer float chamber. Before it gets there, some vapor in the condenser float chamber is drawn into the second stage of the compressor to raise the efficiency of the cycle. The liquid, however, passes through the economizer float valve and goes to the cooler, extracting heat from the chilled water. From there, the chilled water at 42^{O}F is transported to the chilled water coils in the compartments and the cooling cycle is complete. A variety of temperature and pressure controlled switches maintain the proper flow of refrigerant and tower water. The plant works 600 gpm of chilled water between 42^{O}F and 45^{O}F.

6.1.2 EQUIPMENT DESCRIPTIONS AND FUNCTIONS

6.1.2.1 Air Conditioning Plant, Pre-fabricated

Carrier Corporation supplies the pre-fabricated air conditioning package for PAVE PAWS. It includes the 600-ton compressor speed increaser and motor, the controller, the condenser using cooling tower water as coolant, the receiver, the economizer, the thermal purge unit, float valves, cooler.and chilled water loop and assorted piping valves, instrumentation, control switches and sensors.

6.1.2.2 Cooler, Pre-fabricated

The prefabricated cooler contains two distinct sections; the first is the tube bundle section and the other one containing the float box, eliminators, and the economizer. Fresh water flows in the tubes with refrigerant in the shell outside the tubes. Individual coolers for

units and compartments are one of three types; the unit coolers, duct coils and gravity coils. Each plant has its own chiller. The output of both plants is connected into a common main. For make-up fresh water, there is an expansion tank. A chilled water pump boosts the fresh water around the cooling loop. The chiller pump circulates water with a supply temperature of $42^{o}F$ and return temperature designed for $45^{o}F$. Deviation from these values is cause for corrective action.

6.1.2.3 Control Switches and Actuators

Automatic control of refrigerant is attained by interaction of the float valves and the solenoid cut-off valve with a thermal control bulb in the chilled water outlet at the cooler. Actuation of the compressor suction control postioner is from signals of a control bulb in the cooler outlet (discharge) line. This control keeps the refrigerant at a temperature above the saturation temperature so the compressor will pump only super-heated refrigerant and not encounter any liquid.

Head pressure from the compressor is controlled by the high pressure control switch. A chilled water temperature below $42^{o}F$ will stop the compressor motor. Cooling water failure control switch operation stops the compressor at too low supply pressure. An oil pressure safety switch becomes active once an interlocking time delay relay allows compressor motor startup with low oil pressure for 10 to 15 seconds. Gear oil pressure may drop during operation before the compressor main contacts are opened. During startup, pressure must

reach the right level before the timer relay opens the contacts or the controller will be de-energized shutting down the compressor.

6.1.3 OPERATIONAL CHARACTERISTICS

The air conditioning plant as manufactured by the Carrier Air Condition Company is designed to deliver 600 tons of refrigeration, however, the equipment can be operated at reduced capacity due to any of the following: operator choice, a reduction in demand sensed by the controls, a less than optimum setting of the controls and/or deterioration of the material condition of the equipment.

The system is, of its nature, complex. It is made up of seven major types of distribution systems: electrical, mechanical, tower water, refrigerant (gas and liquid), oil, fresh water, and air with both electrical and mechanical power and controls. None of the components in the equipment is, of itself, very complex. Collectively, the system requires a highly trained and motivated operator with a great deal of experience, to correctly evaluate its performance and adjust its operating characteristics to meet the loads. Furthermore, when the demand for cooling exceeds the capacity of the operational air conditioning equipments, the operator has no clear choice in the options available to achieve the maximum benefit from the existing capacity. This is due to the complexity of the relationship between the data available to him and his immediate goals. Whatever action he takes is a compromise and there is no clear real time indication of how successful he is.

6.1.4 Subsystem Reliability Experience

The following table ranks the subsystems in the order of increasing commercial experience reliability, as expressed in MTBMA (Mean Time Between Maintenance Actions) in hours. This ranking has been established through interviews with air conditioning manufacturers, installers, and users. The ranges illustrate the results of variations in environment and severity of services.

SUBSYSTEM	MTBMA, Hrs.
Control system and expansion valve	800-10,000
Compressor	5,000-20,000
Motor	2,000-30,000
Condenser	20,000-100,000
Evaporator	20,000-250,000

In military applications, this relative ranking is generally preserved; however, the corrective action frequency can be an order-of-magnitude worse. As discussed earlier, the dearth of failure data frustrated the attempt to derive subsystem MTBMA for the AF applications.

6.1.5 Predicted Industrial System Failure Modes

There is one basic failure mode in air conditioning equipment -- that of failure to absorb enough heat from the "load", which is the basic task of the system.

Sometimes this is referred to as "loss of capacity". This can occur in two senses: first, outright loss of the mechanical and thermodynamic efficiency through system degradation; and secondly, through a misadjusted control system.

Losses of efficiency and capacity are due to one or more of the following general failure mechanisms:

- Corrosion
- Fatigue failure
- Deposit formation
- Fracture failure

These losses of capacity are due to faults in one or more of the following major air conditioning subsystems:

- Control system and expansion valve
- Compressor and motor drive
- Condenser and tower water circulation system
- Evaporator (water chiller) and fresh water circulation system

Ancillary systems such as the fresh chilled water circulation system and the tower water circulation system exist at important interfaces, frequently malfunction, and are the prime cause of problems associated with the air conditioning unit.

Four additional types of fluid systems are included, and these complete the failure mode considerations, inasmuch as they are subject to defect as well as the equipment listed above:

- Primary Refrigerant (R-12, $CCL_2 F_2$)
- Secondary Refrigerant (fresh treated water)
- Coolants -- tower water, ambient air
- Lubricant -- compressor oil

The primary refrigerant can be defective at the time of installation, or may become contaminated by dirt, water or oil through faulty maintenance practices and ineffective drying procedures during sealing of the system. The secondary refrigerant, treated fresh water, may be poorly maintained lacking proper corrosion inhibitors and anti-scale formation additives which will lead to leakage or scale buildup. The leakage may lead to moisture contamination of the primary refrigerant. The coolants, tower water for the condenser, and ambient air for the cooling of the drive motor and compressor may be contaminated with dust or have an abnormally high temperature.

Table 6.1.3-1 indicates how the failure mechanisms are associated with the basic air conditioning subsystems. Several specific failure modes can be identified from an analysis of this information and a knowledge of the design details of the Carrier 600 ton Water Chiller unit.

Moisture contamination of the primary refrigerant is the most frequent cause of system failures. Usually these moisture caused failures are quite extensive and lead to many of the other failure modes identified in Table 6.1.3-1. Table 6.1.3-2 is an expanded list of failure modes categorized by major subassembly and correlated with symptoms and causes.

The following paragraphs provide more detailed insight into the mechanisms involved in several of the major failure modes.

6.1.3.2.1 Control System

There are several control system failure modes and numerous failure points and components likely to fail. The control system has the lowest MTBMA of all A/C subsystems and more troubleshooting actions can be related to control system adjustments, repairs and fixes than any other single A/C subsystem. This is primarily due to the fact that both machine and humans interface with the controls.

TABLE 6.1.3-1. FAILURE MECHANISMS WITHIN AIR CONDITIONING SUBSYSTEMS

1. Expansion Valve and Controls	• Fatigue failure due to on/off cycling in use (normal) • Fracture failure due to over pressure • Deposit formation at valve orifices
2. Compressor	• Abrasive wear of mechanical parts due to contaminated oil • Corrosive wear due to acid formation in oil (freon, water, Oil system)

TABLE 6.1.3-1. FAILURE MECHANISMS WITHIN AIR CONDITIONING SUBSYSTEMS

(Continued)

2. Compressor (continued)	• Fracture failure due to slugging of liquid refrigerant through improper control settings • Fatigue failure of valve components • Catastrophic bearing wear due to loss of oil pressure or oil supply through poor maintenance or misalignment of coupling
3. Motor	• Bearing wear due to lack of lubrication or misaligned coupling • Overheat due to improper control settings or lack of ventilation air
4. Condenser	• Fatigue failure through tube vibrations induced by high velocity liquid flow • Corrosion through presence of corrosive liquids • Fatigue failure through thermal stresses (normal)

TABLE 6.1.3-1. FAILURE MECHANISMS WITHIN AIR CONDITIONING SUBSYSTEMS

(Continued)

4. Condenser (continued)	• Fracture failure through over pressure (poor control.and regulation of tower water) • Deposit formation on tube surfaces reducing heat transfer rate and heat exchanger efficiency - poor strainer maintenance or contaminants in refrigerant
5. Evaporator (Chiller)	• Fracture failure of tube to tube sheet joints due to ice formation - poor evaporator flow control • Deposit formation on tube surfaces due to poor water treatment or contaminants in refrigerant • Corrosive wear due to presence of corrosive liquids in water or refrigerant • Fatigue failure through vibrations induced by high velocity fluid flow across tubes - poor control

TABLE 6.1.3-2. COMPONENT RELATED FAILURE MODES

FAILURE MODE	SYMPTOMS*	CAUSES
(Float Valve and Control System)		
• Pilot valve and/or prerotation vane operator inoperative	Compressor short cycling-system	Generally due to the following:
• Solenoid valve and/or solenoid winding defective	Refrigerant flowing continuously	1. Poor initial setup and adjustment
• Suction pressure switch defective	Compressor runs continuously; loss of cooling capacity	2. Damage to controls from vibration
• Chiller to float valve thermal bulb defective	Compressor will not start; loss of cooling capacity	3. Defective adjustment 4. Corrosion of control elements
• Condenser water pressure switch defective		5. Fatigue failure of control elements (normal)
• Motor control relays sticking		
(Compressor)		
• Capacity control system mis-adjusted	No control over number of compressor cylinders loading or unloading - loss of cooling capacity	Misadjustment or contaminate lubricant. Could also be fatigue failure of control component
• Low oil pressure	Poor control of autovalve loading mechanisms	Worn oil pump, clogged oil strainer filter due to contaminated oil

TABLE 6.1.3-2. COMPONENT RELATED FAILURE MODES (Continued)

FAILURE MODE	SYMPTOMS	CAUSES
(Compressor) (cont'd.)		
• Low oil level	Poor control of auto loading mechanisms increased oil temp.	Loss of oil to refrigerant due to worn compressor
• Mechanical seal failure and oil leaks	Oil leaks, low oil leaks	Excessive vibration of crankshaft due to coupling misalignment
• Worn bearings	Noises from compressor	Excessive vibration due to coupling misalignment or low oil supply or contaminated oil
• Worn pistons, rings, liners	Loss of oil, low oil levels	Contaminated oil, loss of oil pressure, loss of oil supply
• Fractured pistons, rings (Slugging failure)	Noises from compressor, loss of discharge pressure, low temperature rise across chiller	Liquid in suction lines - defective control elements or defective chiller flow control or reduced chiller efficiency
• Discharge valve failure	Compressor runs continuously	Fatigue failure of valve (Normal)
• Suction/discharge valve mechanism failure	Low discharge pressure, loss of cooling capacity	Fatigue failure (normal) or result of slugging failure

TABLE 6.1.3-2. COMPONENT RELATED FAILURE MODES (Continued)

FAILURE MODE	SYMPTOMS	CAUSES
(Electric Motor)		
• Windings damaged	Loss of power to compressor, loss of overall cooling capacity	Poor ventilation clogged with foreign material, high ambient air temp.
• Bearings worn, spalled	Noises from bearings ultimately seizure of motor, rapid loss of shaft power to compressor, high power drain, loss of rpm	Lack of lubrication and maintenance, vibrations due to coupling misalignment
(Condenser)		
• Condenser tube/tube sheet leaks	Loss of refrigerant, loss of overall cooling capacity, moisture contaminated refrigerant, corrosion at joints and damage to compressor	High pressure at tower water circ. system, poor pressure regulation and pressure relief
• Deposit and scale formation on tubes (waterside)	Reduced heat exchanger efficiency and loss of overall cooling capacity small temp. drop across condenser	Defective water strainers and strainer maintenance

TABLE 6.1.3-2. COMPONENT RELATED FAILURES MODES (Continued)

FAILURE MODE	SYMPTOMS	CAUSES
(Condenser) (cont'd.)		
• Deposits on tubes refrigerant side	Reduced heat exchanger efficiency and loss of overall cooling capacity, small temp. drop across condenser	Worn compressor, defective oil well, increase the rate of formation (oil contamination due to above)
(Evaporator-Chiller)		
• Chiller tube/tube sheet leaks	Loss of refrigerant, loss of overall cooling capacity, moisture, contaminated refrigerant, corrosion at joints and damage to compressor	Corrosion at joints due to lack of water treatment additives
• Deposits or scale formation on tubes (waterside)	Reduced heat exchanger efficiency and loss of overall cooling capacity, small temp. rise across chiller	Lack of water treatment additives
• Deposit on tubes (refrigerant side)	Reduced heat exchanger efficiency and loss of overall cooling capacity small temp. rise across chiller	Oil contamination of refrigerant due to worn compressor

Other factors contributing to a high control system failure rate are the large number of connections (both electrical and mechanical fluid) and the use of analog control schemes. The initial setup of analog controls is subjective and based somewhat upon human opinion or judgment. Subsequent load control or demand is also subject to human judgment, and usually is at cross purposes with meterological and environmental conditions which influence system efficiency. The following control system failure modes have been identified:

1. Sensor fatigue and degradation of signal-to-parameter relationship due to vibration, heat and operational cycles.
2. Loss of control parameter signal
    a. open or short circuit -- abuse and installation
    b. noise and cross talk
3. Adjustment of actuators into an unstable control response or impossible control response
4. Corrosion of contacts and mechanisms due to moisture and airborne contaminants.

The highest single cost of repairs in the air conditioning system can be the setup and "tuning" of the controls. Field experience has shown that the setup of unit controls takes about 6 to 8 hours under normal conditions. Troubleshooting of controls, however, can take up to 100 man hours as a maximum example. If the initial setup of controls is faulty this can lead to numerous unnecessary inspections and repairs to other elements of the system.

6.1.3.2.2 Compressor

This subsystem is considered highly reliable provided proper maintenance is adhered to, and if there is no abuse. Two basic mechanisms, mechanical wear on reciprocating and rotating bearing surfaces and the fatigue failure of components subjected to stress reversals, are the two main failure mechanisms. Impact with liquid refrigerant and general overheating are two other mechanisms of failure that are less probable, but do occur. Deterioration of mechanical seals and bearings has been identified with several maintenance related causes:

- Misalignment of shaft coupling to electric motor drive
- Loss of oil and inadequate oil make-up
- Addition of improper oil and/or contaminated oil

The use of unsuitable oil; chemically unstable, too viscous, containing impurities (especially moisture), or the use of too much oil even of high quality, will likely cause excessive wear, friction and deposits resulting in decreased plant efficiency. Compressor lubricant failure can be produced by the following:

(A) Pour point too high -- forms solid waxes at chiller and expansion valve which reduces heat transfer rate and system efficiency by clogging chiller surfaces. Reduces system flow rates by clogging valves and piping. These mechanisms occur

only when oil contaminates the refrigerant in some quantity and is carried throughout the system. Initial causes are generally associated with compressor.

(B) In reciprocating compressors, viscosity should be matched to the mechanical tolerances with respect to operating temperatures and compressed refrigerant pressures. Similarly, the compressor bearing tolerances and working loads and temperatures require careful selection of proper lubricant viscosity.

(C) Impurities in oil, such as dust, dirt, scale and especially water. Solid impurities cause direct wear on the bearings and piston, ring, liner and surface seals. Water in oil causes a three-fold problem. Water in oil leads to water in the refrigerant, if oil does get into the refrigerant circuit.

(1) Water tends to freeze and form ice, reduce flow of refrigerant and reduce system efficiency.

(2) Water, oil and freon tend to form acids after periods of time, and cyclic reheat that corrode piping joints and seals which lead to system leaks and loss of refrigerant and ultimately loss of efficiency.

(3) Water tends to form emulsions in the oil and, if water and oil are present in the refrigerant, deposits will form in the condenser. The deposits generally will reduce the heat transfer areas and condenser efficiency.

(D) Freon in oil causes the oil to froth when the refrigerant boils. This results in a sudden loss of oil to the lubrication circuit. Freon in oil constitutes oil dilution and a reduction in effective viscosity.

High oil consumption is generally caused by worn rings, pistons, and liners, which result in oil pumping to the refrigerant circuit.

A good refrigeration compressor oil to be used with Freon 12 should have the following characteristics:

Pourpoint	0^{o}F (minimum)
Flash point	408^{o}F (minimum)
Acidity	0.1 (maximum neutralization number)
Carbon residue	0.3%
Viscosity	450-550 Saybolt Univ. Seconds
Viscosity index	75

An oil having a dielectric strength of 21,000 volts per millimeter when tested in accordance with the ASTM method D117-33 is considered sufficiently pure and dry for refrigerating purposes.

The lubricant should have good chemical compatibility with Freon 12 and have adequate dispursant/detergent additive packages to allow handling of system-originated dirt and moisture.

The oil specified as Federal Specification VVL-825, type II, exceeds all of the above requirements.

The MTBMA for the compressor is reasonably long in comparison with the total air conditioning system, including the condenser and chiller. The compressor problem is compounded by the fact that failures in the control system, condenser, and evaporator, usually have a detrimental effect upon the life of the compressor. There are few important instances where the reverse is true. A reciprocating compressor is the component of the air conditioning system that is most subject to catastrophic failure. This is naturally so since it is the only high stress member of the system and is subjected to the highest count of stress reversals.

6.1.3.2.3 Electric Motors

The failure modes of medium sized (approximately 100 hp) electric motors may range from a simple conductor breakage that results in little damage, quickly reparable without disassembly, to essentially complete internal winding destruction or mechanical failure that requires (at best) an expensive rewind/rebuild procedure. Historically, the electric motor has proven to be an extremely reliable power transducer and for that very reason is.often abused by lack of maintenance, overload, poor ventilation, etc. leading to

shortened service life and sometimes to catastrophic motor failure. Such failures can damage related electrical or mechanical components and greatly compound the cost of the original motor failure.

The following list of electric motor failure modes and related causes can be summarized into two important causes: machine vibrations and overheating. Overheating is due most frequently to poor ventilation or overload. Vibrations are due to shaft coupling misalignment. Electric motor vibrations lead to ball bearing wear.

(A) Electrical Components

(1) Winding

Open Circuit - mechanical damage vibration

Short Circuit - mechanical damage

- Insulation loss due to overheat, overload, poor ventilation

(2) Connections

Open Circuit - mechanical damage, vibrations

Short Circuit - mechanical damage, vibrations

AD-A138 576 CONDITION MONITORING TECHNIQUES FOR ELECTROMECHANICAL 2/4
EQUIPMENT USED IN A..(U) HUGHES AIRCRAFT CO LONG BEACH
CA R R HOLDEN AUG 83 RADC-TR-83-180 F30602-81-C-0113

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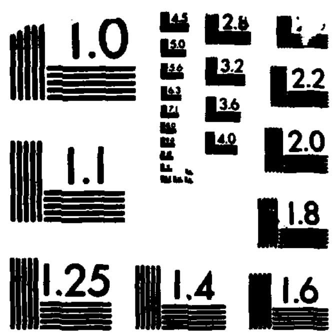

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

(B) Mechanical Components

(1) Rotor

Laminations - mechanical damage

Shaft - misalignment

Seals - vibration

Bearings - defective, incorrect lubricant, no lubricant, vibration, excess heat (overload, poor ventilation), high ambient temp.

(2) Stator

Laminations - mechanical damage

Frame - mechanical damage

Fasteners - vibrations

Ball bearings, like many other components, exhibit a typical life curve as shown in Figure 6.1.3-3. Wear rate is rapid during early hours of service, but settles to an approximately constant and relatively low value for a long period of time. The length of the constant-wear-rate period, which corresponds to the useful life of the bearing, depends upon many factors, including operating load, temperature, lubrication, cleanliness, etc. Eventually, however, a small defect will appear in one of the bearing components, thus marking the end of the constant wear of the bearing. Following initiation of the first such defect, wear rate increases rapidly until catastrophic failure of the bearing occurs. Bearing failures are caused by defects which can be grouped into two basic classes: (1) local defects such as spalls, corrosion pits, Brinell marks and foreign object damage, and (2) distributed defects including out-of-

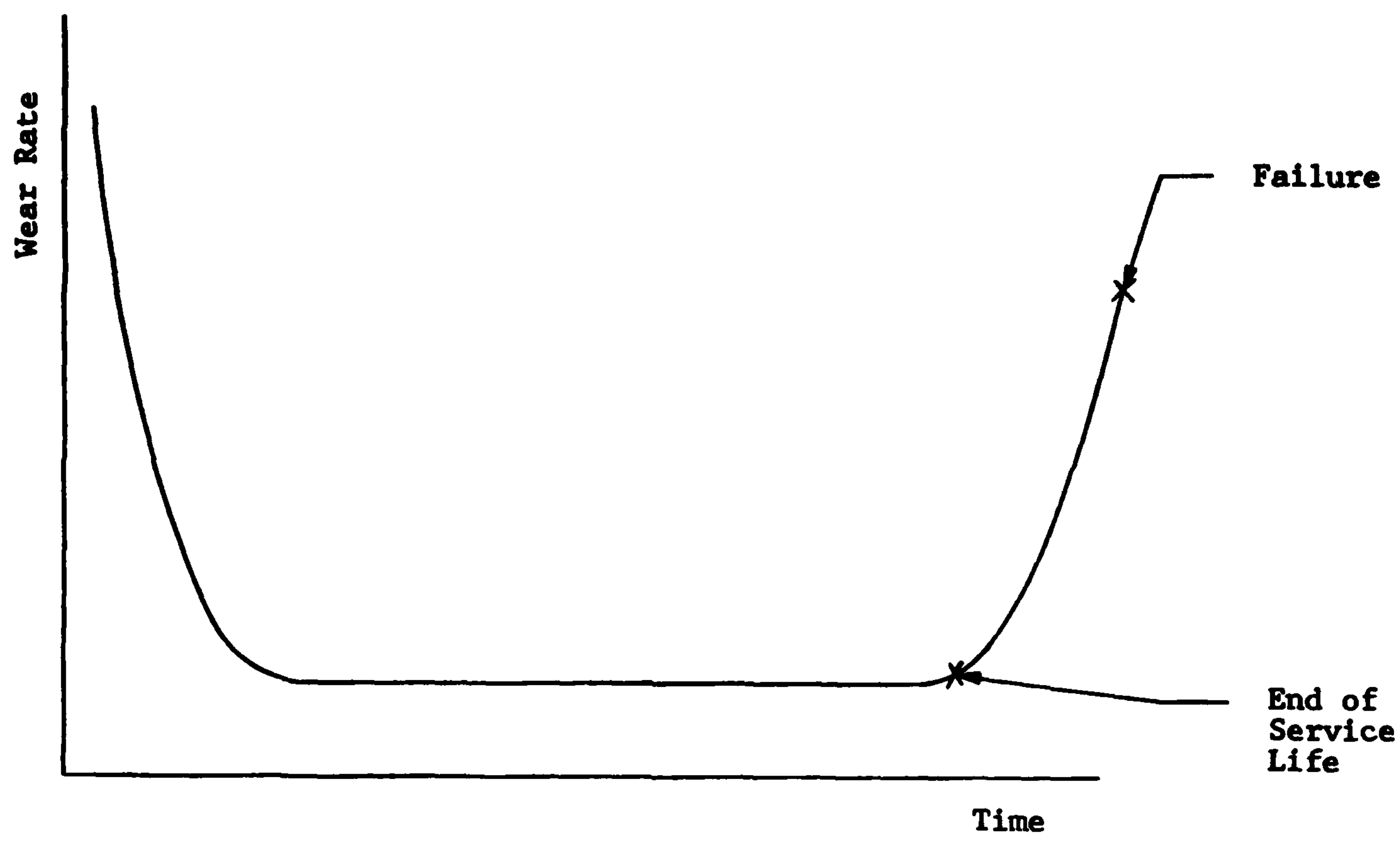

Figure 6.1.3-3. TYPICAL BALL BEARING WEAR RATE CURVE

roundness, unequal ball diameters and misalignment. Early bearing failure can be attributed to a number of possible causes such as (1) a manufacturing defect, (2) mechanical abuse during installation, (3) overload, (4) lubrication failure, and (5) foreign matter. In many cases, causes of early bearing failure can be eliminated by careful design, installation and maintenance.

6.1.3.2.4 Condenser and Chiller

The condenser and chiller are treated together since they are similar in design and are both heat exchangers. Failures of these heat exchangers is characterized by a leak resulting in refrigerant loss or contamination or by deposit formation on heat transfer surfaces, causing loss of heat transfer effect. Important here is the fact that a large critical interface exists between the refrigerant and either treated or fresh water. A leak leads to internal system corrosion of nearly every element of the air conditioning system. These leaks are difficult to detect and repair.

Both the condenser and chiller are subject to the following failure mechanisms that lead to water leaks into the refrigerant system, or loss of refrigerant.

Thermal stress due to cyclic heating and cooling is a normal situation in heat exchangers. A life expenctancy of 10 to 20 years of continuous operation can be expected if no other failure mechanisms are experienced.

Stress corrosion and mechanical wear failure mechanisms are common in tube and shell construction. Turbulence of liquids and lack of adequate tube support reduces the life of the heat exchanger, by wearing the tube to tube-sheet joint. This results in leaks. No appreciable heat transfer loss is experienced as a result of these mechanisms. Stress corrosion, when combined with cyclic thermal expansion, shortens the life to 2-5 years, or by about a factor of 4, depending upon the seriousness of tube oscillations. This effect is caused by improper tube installation, as well as improper tube support relative to fluid velocities.

Electrolytic corrosion mechanisms, when added to cyclic thermal expansion and stress corrosion, can reduce the life expectancy by another factor of two. Sacrificial cathodic protection is a common fix. Causes of this mechanism are complex, but basically are due to the presence of two highly dissimilar metals being present in an electrolyte (oil-water-freon). The results of this failure mechanism are leaks at tube to tube-sheet joints, plus pitting of the tube surfaces, all of which can result in leaks and a reduction in heat transfer.

Occasional over-pressurization of the condenser cooling water supply, bursts control elements that are connected directly to the refrigerant circuit, and allow moisture contamination of the refrigerant during shutdown periods.

Improved tube materials have been recommended, such as cupronickels. This material would resist corrosion and stress corrosion, with a small decrease in heat transfer rates. Alternatives such as monel or stainless are not practical, due to the fact that there are orders-of-magnitude decreases in the heat transfer coefficient, resulting in poor heat exchanger efficiency.

Scale and deposit formation on condensers is related to poor tower water strainer maintenance and is a normal maintenance problem. Deposit formation on the chillers is controllable, through adequate treatment of the chilled water. Contamination of the refrigerant with oil and water leads to deposit formations on the refrigerant sides of the heat exchangers, primarily at cool locations. This results in loss of heat transfer rates and loss of refrigerant flow rate, which compounds the heat transfer problem. Poor lubricant selection aggravates this situation.

Corrosion formation on heat exchanger surfaces has a two fold effect. Primarily, it forms an insulative coating, which reduces heat transfer rates. However, there is usually a loss of overall material, and a corresponding reduction in wall thickness, associated with corrosion mechanisms, which tends to improve heat tranfer rates. The net effect is an insignificant change in the heat transfer rate until the

corrosion is cleaned from the tubes, at which point, the heat transfer rate is improved through reduction in thickness. However, the potential for leaks and mechanical damage has increased greatly.

6.1.3.2.5 Refrigerant Contamination

The Freon 12 (CCL_2F_2) is the working fluid in the 600 ton Carrier air conditioning system and its chemical characteristics and thermodynamic properties must be maintained, in order to ensure the thermodynamic performance of the air conditioning system. Air, oil, water, and dirt can contaminate the refrigerant, resulting in loss of system performance, and the development of long term degradation of components. Air contamination is not normally serious, but due to the fact that air contains water vapor, it can have detrimental effects. Oil contamination has been discussed earlier in the report, as causing heat exchanger and control element problems. Dirt in the refrigerant acts as both an abrasive and a fouling agent.

The most serious refrigerant contaminate is water. There are several mechanisms by which water can contaminate the refrigerant:

- Leaking connections, joints, gaskets, seal at water to refrigerant interfaces
- Air left in system, at time of recharge or initial charge.
- Defective refrigerant

- Defective atmosphere-to-refrigerant seals. Porous substances, such as gaskets, teflon seals, rubber seals, etc., allow equalization of the partial pressure of water vapor inside the refrigeration system with the partial pressure of water vapor in the atmosphere, regardless of total pressure differential.

The moisture in the refrigerant deteriorates the metal surfaces of the air conditioning equipment by corrosion and rust formation mechanisms, which leads to loss of pressure seal in most cases. This effect tends to allow more refrigerant contamination, or loss of refrigerant. Moisture increases the tendency to freeze up the evaporator (chiller). Moisture accelerates valve failures, and makes the slugging phenomena more serious.

A slow reaction of Freon 12 with water produces both HCL and HF acids at a rate of about 0.005 grams/liter of H_2O/year. This is normally an insignificant acid build up. This hydrolysis is greatly accelerated, when the moisture content exceeds the saturation limit of Freon 12. Figure 6.3.1-4 illustrates the solubility of water in Freon 12. In the 600 ton system, this saturation value corresponds to less than an ounce of water in the system. Under any condition, a small leak could quickly saturate the freon and allow acid formation to proceed at maximum rates.

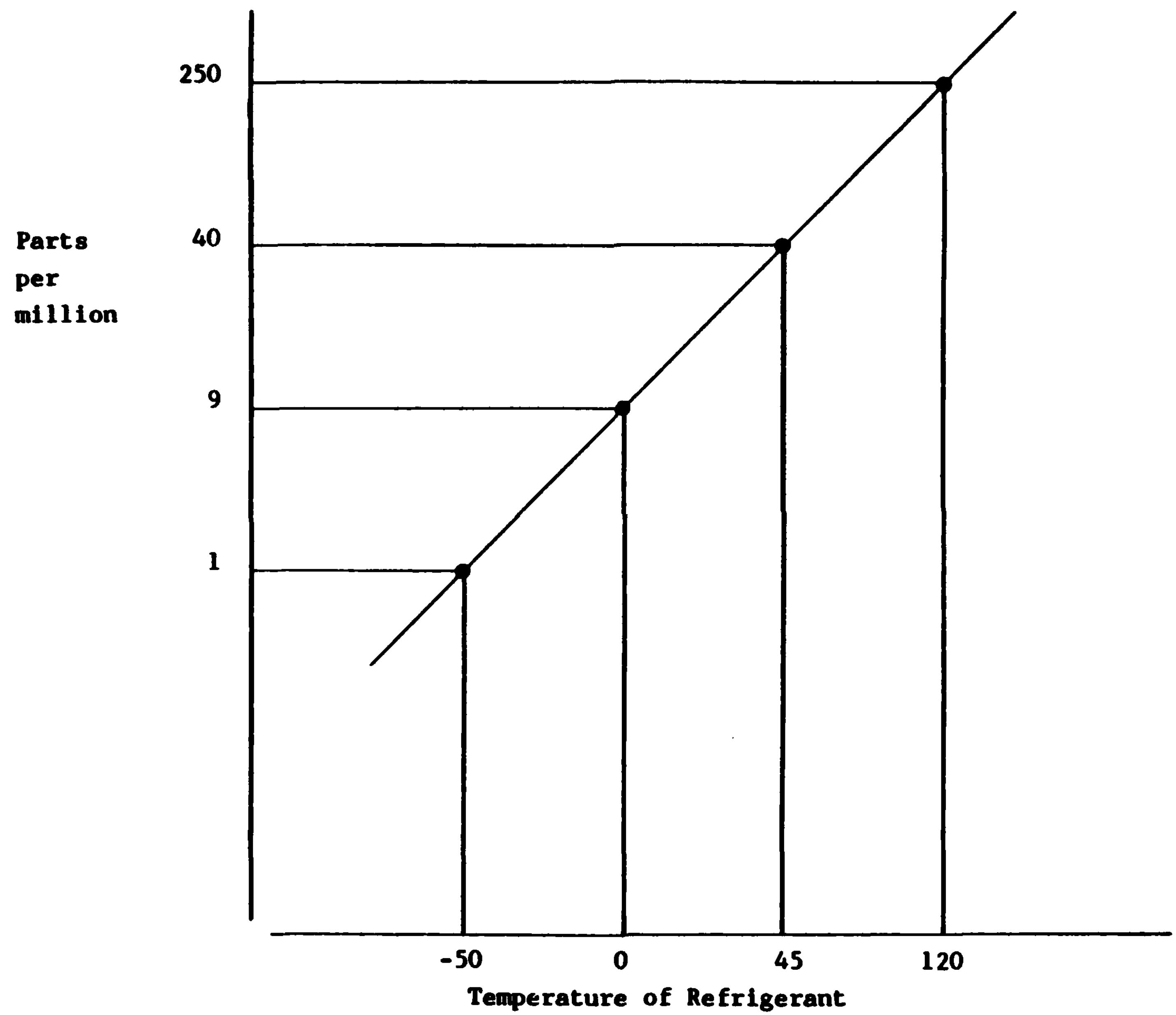

FIGURE 6.1.3-4. SOLUBILITY OF WATER IN FREON 12

A "copper plating" failure mechanism is associated with oil, water, and refrigerant chemical interactions. This phenomenon is a slow process, but is accelerated by presence of moisture and acids, especially in the high temperature regions of the equipment. "Copper plating" is noticed in the compressor bearings, resulting in high bearing friction and eventual wear. Superior refrigerant oils usually preven[illegible] this phenomenon from becoming a failure mechanism.

Oil and moisture contaminants alter the thermodynamic properties of the working fluid whether they are in solution with the Freon 12, or not. This is due to the high circulation rate of the refrigerant. Free water will be circulated in "slugs" throughout the system. Oil is infinitely soluble in Freon 12. The contaminants tend to lower the vapor pressure of the refrigerant, resulting in a decreased efficiency of heat transfer at the evaporator and a loss of cooling capacity.

Principal Refrigerant Failure Modes

Moisture contamination of the primary refrigerant is the most frequent cause of system failures. Usually these moisture caused failures are quite extensive and lead to many other failure modes. In contrast to this, failure of some of the air movers and cooling coils does not have serious ramifications upon the performance of the rest of the air conditioning equipment.

The principal sources of induced failures fall into four categories:

1. Fluid Contamination
2. Environmental Problems
3. Electrical Problems
4. Mechanical Problems

These often combine in a cause/effect relationship. In a mature system, the system failures should follow the theoretical modes more closely, and the distribution should be more evenly spread over the various wear mechanisms.

6.2 DIESEL GENERATOR DESCRIPTION

A diesel generator equipment breakdown structure divides into three major subsystems, engine, engine support, and generator. The engine subsystem consists of the diesel (less major assemblies), starter, combustion air intake, governor, fuel, exhaust, coupling, cooling and instrumentation/alarms. The engine support subsystem supplies starter air, fuel, exhaust disposal, lubrication oil, water and cooling of engine operating fluids. The generator subsystem consists of the rotor, starter, bearings, lubrication, cooling, field excitation and instrumentation/alarms. Further breakdown to the piece part is deferred to developing troubleshooting and repair procedures and for provisioning spares which is beyond the scope of this effort.

6.2.1 DIESEL GENERATOR FAULTS

Diesel engine faults can be roughly classified into groups of those that affect the engine performance and efficiency and those that affect component integrity but not the engine efficiency or performance. An example of the latter fault type is worn valve guides for which engine performance is not significantly affected, but oil consumption may become objectionably high and lead to other faults that would eventually degrade engine performance.

The diesel engine-generator efficiency and performance is of prime importance in any effort to establish its condition. The output in Watts of electrical power per pound of fuel consumed (Watt/lb-fuel) is a time-proven measure of system condition. Techniques for accomplishing this and the measuring equipment are well developed and proven. The measurement of overall diesel generator set performance, however, does not constitute a comprehensive check out of engine faults. The engine and generator can be fuel efficient but operating with defects that will eventually lead to significant performance degrading faults. These defects should be detected and used to establish the real condition of the machinery. Table 6.2-1 lists the important faults expected to occur in any large diesel engine. The faults are classified in the table as to whether they affect performance and the nature of the corrective action required. Note that some of the faults are easily repaired and others require extensive engine overhaul.

TABLE 6.2-1. DIESEL ENGINE FAULTS AND DEFECT EXAMPLES

FAULTS AND DEFECTS	EFFECT UPON PERFORMANCE	NATURE OF CORRECTIVE ACTION
Poor Compression	Hard starting, but not a serious performance effect usually high oil oil consumption	Extensive repairs or rebuild, could be minor repair if only a burned valve - Open and Inspect
Faulty injectors	Serious effects	Replacement of injectors if detected early--can lead to serious wear in some cases
Defective governor and control linkages	Serious effects	Simple adjustments and minor repair
Worn bearings	Small initial effects on performance but can lead to catastrophic failure to catastrophic failure	Minor to major repairs if detected early - extensive rebuild if not detected in time
Scaled water jackets and overheating problems	Difficult to detect by performance measurements in early stages but can lead to seizure and catastrophic failure	Major repairs
Poor lube oil circulation or defective lube oil system	No performance effect unless allowed to progress until bearings fail	Major repairs if detected early--Major rebuild if allowed to progress
Defective turbocharger of worn blower	Significant effect upon performance	Usually minor repair unless the items were catastrophically failed
Parasitic power losses associated with accessories	Significant effect upon performance	Usually a minor repair
Parasitic power losses associated with shaft alignment, bearings, rods, etc.	Significant effects upon performance	Usually a major repair

It is concluded from the above discussion that both types of engine faults should be detected and some of the faults should be isolated in the event that a serious performance-affecting fault could be corrected by a simple replacement of parts. An example of this is clogged injector nozzles. The performance would be greatly affected but the repair is relatively simple and is classified as a minor repair and adjustment.

Overall diesel generator performance measurement has additional advantages. If the engine is tested and found to have a relatively straight-forward defect that can be easily repaired, it can be retested after repairs with confidence using performance results. The other advantage of making the measurement of watts/lb-fuel is that the defect could be isolated to the generator.

In the course of a study of the reliability and maintainability of a ship's machinery installation, Wilkinson and Kilbourn of the British Ship Research Association published the following figures on component failures which had been collected from the records on 51 motor tankers over a period of 1 and 4 years, representing a total period effectiveness of 100 ship years. (Table 6.2-2)

The diesel alternator failure information was obtained from the records of sets that operated for widely different periods during a calendar year. The failure frequency in auxiliary diesel engines was approximately the same whether or not the equipment was used frequently or for long periods. Considering usage, MTBF calculations

TABLE 6.2-2. TYPICAL COMPONENT FAILURE RATES (MARINE)

Components	Failure rate Failures/1000 h	Mean time Between Failures, h
Turbo-alternator and controls		
- alternator end	0.007407	135,000
- turbine end	0.05556	18,000
Diesel alternator and controls		
- alternator end	0.008850	113,000
- diesel end	0.09091	11,000
Turbo-alternator system sea water circulating pump	0.005405	185,000
Diesel alternator sea water circulating pump	0.01	100,000
Condenser	0.01176	85,000
Circulating pump	0.04167	24,000

result in a wide range of values. Unfortunately, the quantity of data collected was insufficient to correlate MTBF with equipment usage.

An analysis of stoppages prepared from reports published by the Diesel Engineers and Users Association based on the year 1970 with respect to industrial diesel engines and following 410 recorded events attributed these stoppages to the causes shown in table 6.2-3.

TABLE 6.2-3

Defect Class	% Occurrence
Fuel-injection equipment and fuel supply	27.0
Water leakages	17.3
Valves and seatings	11.9
Bearings	7.0
Piston assemblies	6.6
Oil leakages and lubrication systems	5.2
Turbocharges (excluding damage by intruding foreign bodies)	4.4
Gearing and drives	3.9
Governor gear	3.9
Fuel leakages	3.5
Gas leakages	3.2
Breakages and fractures, other than under other specific headings	2.5
Miscellaneous	2.5
Foundations	0.9
Crankshafts	0.2
	100.0%

6.3 Human Factors in Failure Incidents

To paraphrase Collacott, where operations involve lengthy duty with limited crews under conditions of isolation, it would appear that increasing attention should be given to the effects of boredom, group interaction, lack of instruction, incorrect motivation, ill-defined areas of responsibility, poor control, group-interaction hostilities, poor communications and the many similar causes of irrational human behavior. Canadian authorities produced the following list of human errors and potential causes to be used in aircraft crash investigations.

TABLE 6.3-1

Error	Cause (inherent or temporary)
Errors of judgement	Lack of experience
Poor technique	Poor reaction
Disobedience of orders	Physical state
Carelessness	Physical defect
Negligence	Psychological state

Compared with power and air conditioning, the impact of these factors in the PAVE PAWS prime system operation and maintenance has been greatly diminish- -s a result of automation. Similar benefits can be projected electromechanical area from introduction of continuous on-i ion monitoring.

7.0 CONDITION MONITORING SYSTEM DEVELOPMENT

The previous discussions dealt with the air conditioning and diesel generator failure modes, possible equipment deficiencies, maintenance practice problems, and possible training problems. This section of the report deals with the application of performance monitoring first to the air conditioning system, and then covers the diesel generator application. The monitor system should be developed in five steps:

a. The definition of a set of requirements

b. The conversion of these requirements into monitoring concepts.

c. The definition of parameters and sensors.

d. The mechanization of the conceptual model monitoring system.

e. The evaluation of the model system against the requirements.

7.1 Requirements Definition

Test and diagnostic capability is a significant factor in achieving improved system performance and availability. A systematic approach to establishing and meeting test and diagnostic requirements using condition monitoring opportunities is required to ensure the utility and cost effectiveness of the application in the Air Force environment.

The requirements have been divided into two major categories.

a. User Requirements.

b. Machinery Problem Monitor Requirements.

The requirements are based on several fundamental assumptions:

a. The performance on the air conditioning equipment must be maintained above a minimum threshold.

b. The personnel maintaining the equipment need to derive direct benefits from the monitor.

7.1.1 Sensor/Software Tradeoffs

Before the availability of minicomputers made sophisticated data processing achievable in condition monitoring, manual interpretation of parameter measurements by highly skilled technicians was used along with open-and-inspect actions to periodically measure degradation and predict remaining useful life. The advent of the automatic data processing capability, high speed multiplexers, analog-to-digital converters, etc. led to the idea of instrumenting electromechanical systems such as diesel generators and air conditioning with as many sensors as possible. The attempt was to solve the conservation of energy and continuity equations at all interfaces, to monitor specific performance, and to assess other measures of efficiency, as appropriate. This concept was temporarily abandoned because the reliability prediction for a deployed military system

with such a large number of sensors was too low. It was also recognized that the MTBF could be improved by shifting more to software than hardware dependency for testing. This assumes required diagnostic and prognostic information can be extracted with a smaller number of sensors using the more sophisticated ADP/software capability. Software is costly: however, the cost can be amortized over all the systems wherein used and, more importantly, software doesn't fail once it has been debugged. In addition, software can be updated more readily and at less cost than a large inventory of hardware. Large fixed installations such as PAVE PAWS require the approach using the greater number of sensors because no large inventory exists over which to amortize software substituted for sensors. Furthermore the overhead already exists for operating a sensor intensive monitoring system.

Without a disciplined approach to condition monitoring, it is possible to over automate, to over instrument the hardware, to focus on one particular technology (such as oil analysis or vibration) and overlook better techniques, or to neglect optimizing the support impact of condition monitoring. For example, significant reduction in or elimination of nonscheduled maintenance would impact spares and provisioning, maintenance manpower allocations, training and technical manuals. A disciplined approach will ensure that condition monitoring contributes to the solution of the problem instead of being an added source of system downtime and maintenance resource consumption.

The reliability of the monitor system hardware should be greater than reliability of the operational system itself. As a general rule the maintenance skills and resources available in the field are considerably less than the skills and maintenance resources at the intermediate level and depot environment.

CONSIDERATIONS IN CONDITION MONITORING

- Eliminate open-and-inspect periodic maintenance
- Trade off number of sensors against software -- don't overinstrument
- Build reliability by substituting software for hardware
- Avoid introducing an additional maintenance burden (The monitor must not become a dominant maintenance problem itself)
- Consider alternatives to oil analysis and vibration monitoring
- Address the impacts of introducing condition monitoring into the AF operational and maintenance environment

7.1.2 User Requirements

The monitor system is a device for communicating electromechanical system performance data to the Air Force personnel who need this data to accomplish their assigned missions. The function performed by this device is currently accomplished through the application of large amounts of skilled manpower. This data is required at the three echelons of maintenance, by other logistics support areas and by the

various Air Force Engineering organizations responsible for improved performance.

7.1.2.1 Organizational Maintenance Data

The electromechanical equipment provides the operators and maintenance personnel with a mass of raw data. Temperatures, pressures, moisture indication, oil and Freon levels are provided through direct reading instruments. Various other indications are available through human observation. These indications include non-instrumented vibration, sound, temperatures, and observation of duty cycles. Finally, by opening certain elements, inspection will provide additional data.

The collection of the data from the instruments and recording in the engineering log requires little skill. It can be accomplished in approximately fifteen minutes by a non-rated watch stander. The non-instrumented operational data can be collected only by personnel with experience and special skills. The actual inspection of opened equipment again requires skill and judgment. The interpretation of all of this data requires specialized training and experience. Interpretation is mandatory in defining either performance or required maintenance actions.

In order to perform preventive or corrective maintenance, beyond routine cleaning and servicing, an identification of the component requiring action is necessary. This is achieved by scheduling certain actions on a routine basis and defining additional items on an "as

required basis" or as a result of the findings of the scheduled actions. The basis for the schedule is time history rather than condition. The Equipment Manual defines a series of symptoms and possible corrective actions which can be used to define maintenance actions that rely on the man's skill to identify the majority of the failures.

In order to meet the above situation and allow the power and air conditioning systems to be maintained at current or improved levels of performance, the monitor system must:

a. Reduce, or at least not appreciably increase the total required maintenance effort.

b. Convert raw data into data which can be understood by lower skill level personnel or more readily understood by a smaller number of high skill level personnel.

c. Provide specific information as to which component is degrading (diagnosis of problem and fault isolation).

d. Reduce the burden of routine observation.

7.1.2.2 Machinery Maintenance Requirement

In the discussions regarding failure modes, specific emphasis was given to the domino effect of particular types of failures. A fair summary of the findings is that the freon refrigerant systems are not tolerant of deferred repairs. When certain types of failures occur, corrective action is mandatory and should be immediate. Without adequate monitoring detection of certain faults is not always achieved in time to take corrective action.

This imposes a specific requirement on the monitor to provide early indication of degradation of critical components and to provide maintenance specific data about these components.

7.1.2.3 Monitor Maintenance Requirements

One of the major problem areas in the air conditioning and diesel generators systems is the electro-mechanical interface. The source of the problem lies in the requirement for cross-training of electricians or mechanics. The monitor system is basically electronic hardware. All of its active components are electronic or electro-mechanical. The electronics are more complex than the electrical circuitry associated with the air conditioning machine. The immediate implication of these facts is that the monitor system can be a maintenance problem.

In order to avoid this situation, the monitor system must include the following characteristics:

a. High probability of differentiation between power and air conditioning failures and monitor failures.

b. High probability of self-diagnosis to a change-out assembly.

c. A mean time between failure (MTBF) comparable to the MTBF of equipment being monitored.

7.1.2.4 CEMIRT Requirement

The shift of maintenance effort from the organizational echelon to the CEMIRT places a requirement to increase the.efficiency of the allocation of resources. Quite often the sites have requested and received aid in correcting the symptoms, rather than the source of the problem. The greatest benefit CEMIRT can derive from a monitor system is the availability of numerical data which defines machinery performance and specifically identifies (diagnoses) the source of a problem. Such data can be used in two ways by the CEMIRT.

a. As advanced data accompanying a request for support, the data can be used in assigning priorities, and allocating both manpower and parts.

b. At the time of the team visits, the monitor can serve the technical specialists as a powerful test, evaluation, and alignment tool.

A secondary function which the monitor should provide to the site is record keeping. While the majority of records kept are economic rather than technical, there is an appreciable burden in the technical area. Reporting of technical data can be improved by the availability of numerical historical data on the equipment serviced by the CEMIRT. The requirements of the CEMIRT are then very similar to those of the organizational echelon.

7.1.2.5 Depot Echelon Requirements

The requirements at the Depot of particular interest are:

a. Availability of quantitative performance data for use in advanced planning.

b. Availability of diagnostic data for determination of immediate repair requirements.

c. Specific information on the condition of repairables at time of receipt.

d. A test/alignment tool which will allow:

1. A reduction in pre-work inspection effort.

2. Evaluation of system performance subsequent to a repair or overhaul.

7.1.2.6 Other Areas Requiring Consideration in PAVE PAWS Monitor Design

A major area which could benefit from the monitor system is that area tasked with engineering improvements in the electromechanical systems. One of the most difficult tasks in product improvement engineering is the collection of adequate data on which to base engineering changes. If the monitor detailed data as collected in real time can be supplied to Engineering organizations in a computer compatible form, such data can be an extremely useful tool in evaluating equipment. A caution must be added to this point -- The mechanization of the monitor and the implementation of this data collection must be accomplished in such a manner that the burden on the organizational echelon is not increased to the point of defeating the primary benefits of the monitor system.

One of the major problems encountered in accomplishing this study was the need for interpretation of the failure data. This problem was related to the need to establish cause and effect relationships between the reported failures. Particular lines in the standard reports including the following can be directly derived from the monitor data output.

Serial Number

First Indication of Failure

% trouble isolated

Meter Reading

Technical narrative

Cause

Equipment status

The same caution applies as in the last paragraph.

7.1.3 Machinery Problem Monitor Requirements

There are many ways of defining monitor priorities for components based on such factors as failure rates, maintenance man hours, parts cost, and performance degradation. The most simplistic approach would involve only an evaluation of such factors. The compressor and diesel lead in all above categories. They require more maintenance actions, have the highest parts cost and cause a total loss of capability when they fail or are down for maintenance.

Using a slightly more complex set of evaluation criteria requires that a cause/effect relationship.be established, in addition to the simple numerical evaluation. When this additional element is added, a set of system problems can be identified. Defining the monitor to detect these problems rather than to examine specific components, provides a better foundation for establishing machinery based requirements for the monitor system.

7.1.3.1 Freon System Moisture

This is the number 1 problem in freon refrigerant systems. A large percentage of compressor failures are traceable to water contamination and contamination by water corrosion products.

Any monitor system applied to the air conditioning system must include a device for determining the moisture content of the freon. The data from this device should provide the following output:

a. System moisture content is acceptable

b. System moisture is increasing - service dehydrator/purge unit

c. System moisture content is unacceptable - locate fault, repair and decontaminate system.

7.1.3.2 Tower Water Subsystem

This subsystem includes the condensors, the flow and pressure regulators valves, and miscellaneous plumbing. The failure mode analysis indicates that there is a definite cause/effect relationship between this subsystem and the freon moisture problem. The water regulating valves in this subsystem are among the high failure rate items and the condensor, while not among the highest reported-failure rate items, is costly to repair and requires extensive preventive maintenance action.

A monitor for this subsystem must provide the following data to the user:

a. Overall system performance evaluation:

   1. Equipment Acceptable
   2. Equipment degraded Reduced Capability
   3. Equipment degraded Non-Operational

b. Diagnostics for reduced or lost performance:

   1. Identify degraded component, or
   2. Identify degraded component group, and
   3. Identify possible monitor failure

In addition, data on the heat transferred to the tower water will be required to check the performance of the chilled water and freon subsystems.

7.1.3.3 Electrical and Control Subsystem

The subsystem includes the electrical power controller, the pressure/temperature sensing switches and circuitry, and the compressor motor. It also includes the majority of the system interfaces. Some of the critical interfaces are:

a. Compressor to tower water pressure
b. Compressor oil pressure to electrical control

c. Freon suction pressure/temperature to compressor control

d. Electrical power to mechanical drive power

The subsystem also includes two of the high failure rate items; the motor and the motor controller.

These equipment oriented factors are supplemented by a personnel training factor due to the electro-mechanical interfaces. Finally the majority of the critical system tests and alignments are performed on the components within this subsystem giving the subsystem a large requirement for scheduled maintenance hours both in number and skill level.

Due to the criticality of this subsystem, the monitor must provide data on its status. This data must include:

a. Motor Condition

1. Condition acceptable
2. Condition degraded
3. Reason for degradation
   - overheat
   - electrical unbalance
   - excessive vibration
4. Probable cause of degradation

b. Automatic control system status

   1. No detected faults

   2. Specific function or component failed or degraded

c. Total electrical power data for use in system performance evaluation.

7.1.3.4 Freon Subsystem

This subsystem includes the compressor, the receiver, the expansion valves, reheater, the freon side of the condensor, the water flow regulator valve and the freon side of the water chiller. The compressor, as stated earlier, has the highest requirement for corrective maintenance manhours of any component in the air conditioning systems. Performance within this subsystem is critical to the performance of the complete system. Within this subsystem there are interrelated malfunctions in which a failure of one component results in damage to another component. An example of such a malfunction in a reciprocating compressor is a failure in the expansion valve, which allows liquid freon to enter the suction side of the compressor in quantities which exceed the capability of the preheater. Under these conditions, the liquid freon can reach cylinders resulting in damage to the compressor.

In addition to the above, this subsystem places demands on the higher skill levels during PM actions. Exclusive of the test/adjustment problem discussed in the last paragraph, the only other regularly scheduled tests are associated with this subsystem.

A monitor for this subsystem must provide the following data:

a. Subsystem operation is acceptable.

b. Subsystem operation is degraded with reduced capability.

c. Subsystem operation is non-acceptable.

In the case of (b), above:

a. Identify the degree of degradation

b. Identify the probable source of degradation, (responsible component).

c. Identify the condition responsible for degradation, for instance:

- Low on Freon
- Contaminated Freon

In the case of (c) above:

a. Identify the rejected function

b. Identify the failed or degraded components

7.1.3.5 Chilled Water Subsystem

This subsystem includes the water chiller, the chilled water pump, the chilled water distribution system including plumbing and the remote loads. The only high maintenance item in this subsystem is

the chilled water pump. In terms of PM inspection and test, the pumps and the chiller require an open inspection operation. The distributed loads require extensive cleaning, which will not be eliminated by monitoring. The actual failure rates in the plumbing and remote loads are currently very low, and are of a nature that makes them difficult to reduce by any method. The highest failure rate item in this portion of the subsystem, (excluding defective lagging and other such problems), is in the remote thermostats. These failures are directly attributable to operator adjustment. A potential problem which has not been currently substantiated is fouling of the subsystem due to the use of hard tap water for make-up water. If this problem develops, it can be detected in two ways: the first is by an open and inspect technique, the second is by checking the thermal efficiency of the chiller.

The monitor for this subsystem should provide the following data:

a. Subsystem is acceptable

b. Subsystem has degraded to reduced capability

c. Subsystem has degraded and is unacceptable

In the case of b and c above the monitor should break the system into three major elements. . .

1 - The pump

2 - The chiller

3 - The load

and define the degree of degradation attributable to each.

7.1.3.6 Diesel Engine

Within the diesel, it is necessary to fault isolate between upper crankcase and lower crackcase problems. Furthermore, upper crankcase degradation or failure must be isolated to the faulty cylinder. It is less important to isolate within the faulty cylinder, where the cylinder must be opened to correct the fault, regardless of the cause. In this case, the final fault isolation takes place as an open-and-inspect action. To minimize down time and the opportunity to incur maintenance - induced failures, it is desirable to restrict open-and-inspect actions to known faulty cylinders. Lower crankcase problems tend to require extensive disassembly for inspection and repair (such as with the crankshaft).

7.1.4 Status Reporting

The data provided by the monitor as defined in the preceding paragraphs is adequate to completely define the performance at the system level. However, in the situation where the performance levels are adequate, there is no real need to provide the data for the subsystem level.

The data presented to the personnel at the organizational level should be organized as shown in the following logic:

1 - If all refrigeration machines are within performance limits, provide only this status.

2 - If one or more machines are OFF, report the machines as OFF, and give last available performance status.

3 - If the performance of one or more machines is unacceptable, define the nature and degree of problem, i.e., reduced capability or non-operational.

7.2 DEVELOPMENT OF MONITOR SYSTEM CONCEPT

The following paragraphs develop a concept for monitoring of this system. The concept is developed on a sub-system by sub-system basis.

While there are hardware implications throughout this development, only concepts and methodology are defined. The development of a hardware system is reserved for a subsequent section of the report.

7.2.1 Freon Moisture Monitoring

Moisture is currently monitored by looking for ice through a peep hole which can only grossly identify the condition of the system as acceptable or unacceptable. Moisture monitors which provide numerical readings are available. The use of one of these devices provides a skilled operator with quantitative information and allows him to make better judgments. If accurate records are kept on the quantitative information, the skilled operator can make judgments which will allow him to perform preventive actions, such as dehydrator replacement, as required, rather than on a routine basis. If this information is

plotted on a graph, data indicating the rate of introduction of moisture to the system becomes available. Analysis of this data can eliminate the need for testing and inspection to determine whether leaks have developed. Further, this rate-of-change data gives much earlier warning of contamination, allowing corrective action to be taken prior to the occurrence of moisture induced secondary failures.

Examination of this system in terms of the requirements established earlier, shows that this approach fails to meet the requirements in two primary areas:

a. It actually increases the amount of manually recorded data required at the organizational echelon.

b. It does require skilled personnel.

The functions associated with this system are:

a. collection of data
b. logging of data
c. storage of data
d. analysis of data
e. presentation of data (if graphing is used)

None of these functions are actually performed by a monitor which simply makes the data available.

If a data logging system is connected to the monitor, functions (a), (b), and (c) are transferred to the resulting monitor system. With

some types of data loggers, for instance an analog recorder, function (e) may also be transferred to the machine. This leaves only the analysis function unattended. Looking back to earlier discussions, the high skill level requirement remains.

Consideration of the detailed relationships between time and moisture content in a Freon refrigeration system is necessary to define the required analysis.. The mechanisms by which water could be introduced into a system were discussed in detail. A natural and unavoidable phenomenon is the low level seepage past seals, gaskets, and valve packings. Assuming no failures, this seepage adds moisture at a relatively constant rate. The dehydrator in the system is designed to trap moisture at a comparable rate. Chemical dehydrators have a finite capacity, therefore the rate at which they absorb moisture decreases as the amount of trapped moisture increases. Plotting water content versus time gives a curve with a shape similar to ocean waves. The crests of these waves occur at the time when the dehydrator is serviced or purge unit operated.

If the "tight" system defined above develops a small leak at an air to Freon interface, the rate of contamination will increase. This leak can occur anytime in the cycle or at any point on the wave. If it occurs in a trough it will not immediately give an out-of-tolerance moisture reading. The slope of the curve will change immediately, since this function is the algebraic sum of the rate at which water is entering the system and the rate at which it is being trapped.

If the same "tight" system develops a leak at a water to Freon interface, the rate of contamination is much greater than in the case of an air to Freon leak. In general, a leak of this type will drive the moisture content beyond allowable limits in a fraction of the time required for the normal or "tight" system cycle.

The introduction of water into the system as a result of a maintenance action will result in a step-function in the curve, since the water is introduced in a "slug" and the dehydrator traps water at a fixed rate. This case requires a different set of decisions, due to the transient nature of the condition. The dehydrator may be capable of coping with the problem, depending on the condition of the dehydrator. To make such a determination the time position on the dehydrator cycle and the height of the peak must be known.

Understanding the characteristics of the moisture failure modes allows the generation of the logic tree shown in Figure 7.2-1. This logic is relatively straight forward. It defines two acceptable situations, two specific maintenance actions and, in the two remaining cases, the degree of failure and fault identification. The problem with the system lies in subjective elements in the failure path -- how slow is "slowly", what is a "step-function", and what are the consequences of deferring corrective maintenance.

Referring back to the beginning of this section, the moisture monitor provided numerical data. Numbers are susceptible to manipulation. These manipulations include:

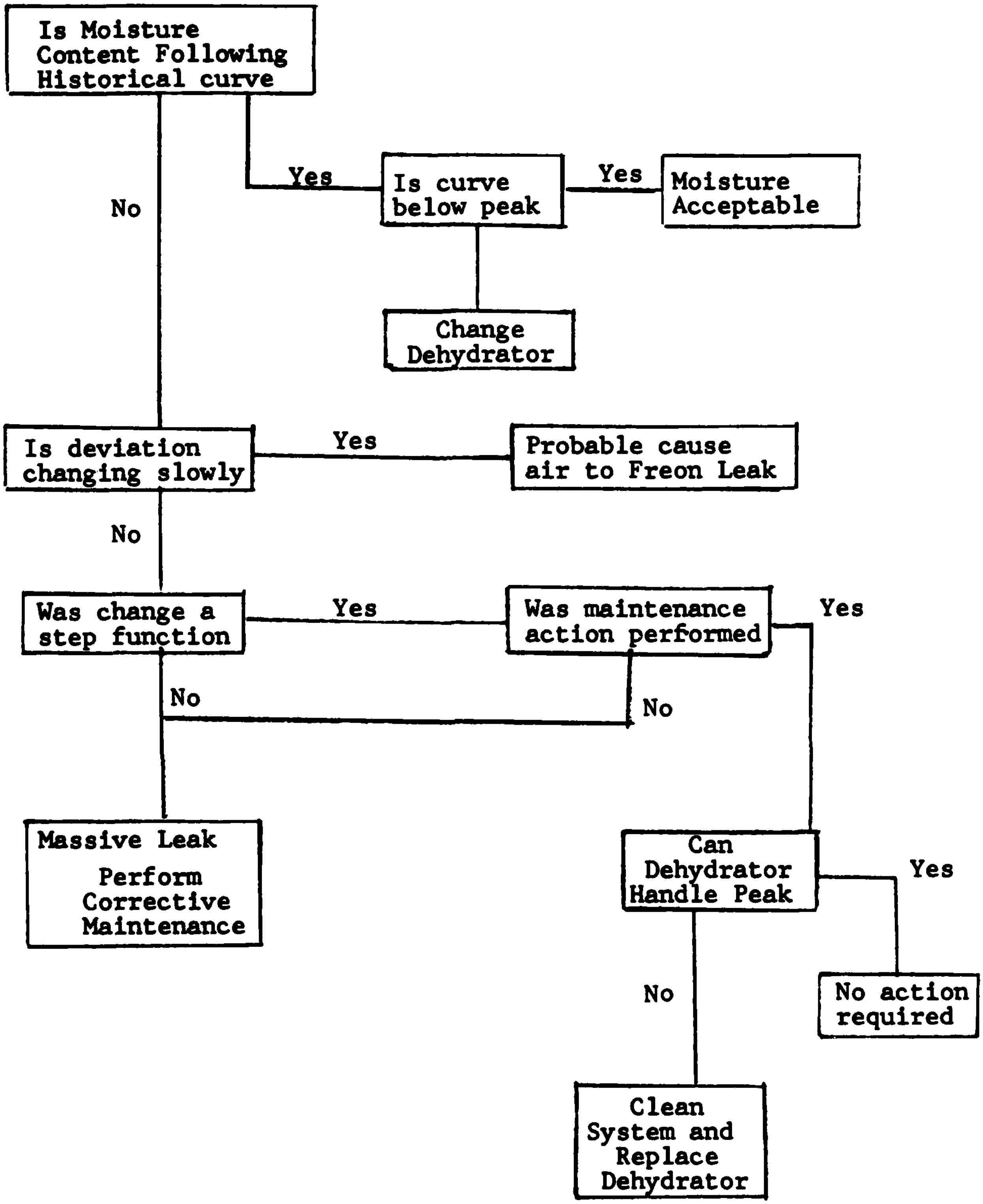

Figure 7.2-1. Moisture Logic Tree

a. development of trend data

b. averaging

c. direct comparisons either with previously acquired sets of numbers or with fixed numbers.

If the monitor is given the capability to convert the moisture content numbers into a number defining the rate of change of moisture content and, in addition, the capability to compare this number with fixed numbers which define the boundaries between slow, fast, and step function; then the subjective elements have, to a large extent, been eliminated. With little further complication, the monitor can provide the operator with maintenance specific data.

Referring back to Figure 7.2-1, there are two areas in which the corrective action is not completely defined. These both involve location of the leak. The measurement of moisture itself cannot provide solutions to these problems. If certain other data is available, further logical conclusions can be drawn. Some instances are:

a. a water flow regulator valve which cannot maintain the specified flow can provide, through its pilot line, access for air

b. a condensor which has had high water flow rates for sustained periods may have developed leaks

c. a chiller which has experienced a temperature excursion to a point near freezing may have developed leaks.

A skilled operator or maintenance man will be able to relate these facts, providing he is aware of them and, in some cases, reduce the number of components which must be examined.

If the monitor is given access to the numbers defining the above occurrences, it can extend the logic tree of Figure 7.2-1 and provide an indication of the most probable failure areas.

The final factor which must be evaluated is the degree to which the monitor failures can affect maintenance.

Only two of the many cases available are considered here, other elements are considered in later sections of this report.

The first case is that where only the numerical readings have been provided. The discussions of failure modes define interrelationships between contamination and performance. Given adequate skill, the operator has available other data which will allow him to identify erroneous data from the instrument.

The second case is the situation where the moisture monitor has access to data from other sources. There are specific relationships between pressure and temperature where Freon exists as both liquid and gas in the same container. The refrigeration system has this situation in the chiller and in the condenser. The monitor can

perform a positive self-test by comparing its reading with the conditions existing at these points. It can perform an even better test by checking to see if there has been any change in these relationships.

To Summarize:

a. The moisture contamination problem can be defined in terms of a relatively straight forward logic tree.

b. The simple shift to a moisture measuring instrument which gives numerical data helps the situation by detecting the fault earlier.

c. A data collection system further reduces maintenance man hours and can in some cases improve the quality of the data.

d. Inclusion of a number manipulating capability reduces the skill levels required by eliminating certain types of subjective decisions.

e. Provision of a means of comparing the moisture content data with data from other sources can reduce corrective maintenance man hours by providing better diagnostic data.

f. A monitor with the characteristics defined in (e) has the capability to define its own condition.

7.2.2 Condensor/Tower Water Subsystem

The primary function of this subsystem is to remove heat from the compressed Freon gas. This function is accomplished in the condensor. An evaluation of this function defines adequately the performance of the condensor. Quantitative evaluation of this function is too complex for the highest skill levels available. The equivalent evaluation is accomplished through a PM open-and-inspect action.

The mechanisms which directly affect this performance are:

a. fouling of the condensor either on the tower water or Freon side
b. entrapment of non-condensable gas in the Freon side
c. improper water flow rate - either high or low

The data required for evaluation of this function includes:

a. tower water inlet temperature
b. tower water outlet temperature
c. Freon temperature and pressure
d. water mass flow rate through condensor
e. a set of design constants for the condensor

This data generally coincides with that currently available on the installed instruments or provided in the technical manual. The mass flow rate is not currently instrumented. The current method of

instrumentation is not compatible with an automatic collection system.

The condensor in commercial systems is commonly used as a laminar flow meter. If the pressure drop across it is known there are well defined equations for the flow.

A logic flow for the condensor is shown in figure 7.2-2. This logical flow, in theory, could be followed by a maintenance technician, in diagnosing the system. The relationships however, are extremely complicated, and involve an understanding of thermodynamic equations.

From this logic tree, there are two paths which lead to checks of other components in the subsystem. The two highest failure rate items in the subsystem are the pressure regulator valve and the flow regulator valve. *Both of these components are equipped with manual* bypass valves to allow for emergency operation. Operating the system with these components either malfunctioning or by-passed reduces condensor life.

It is possible that the performance check on the condensor would not detect a malfunction or by-pass on one, or both, of these components.

The data required to check these components is included in the data required to check the performance. It includes:

a. tower water pressure at condensor input

b. tower water flow

c. Freon pressure

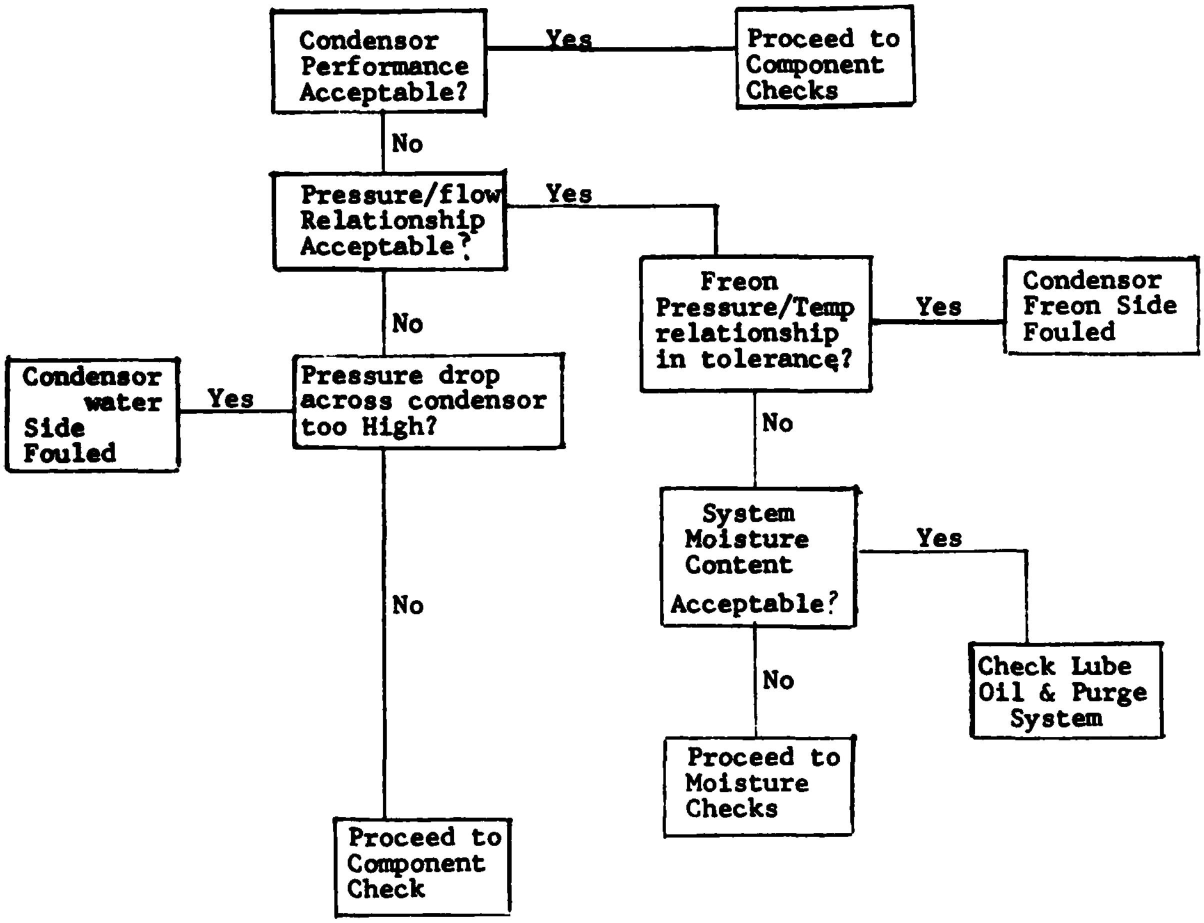

FIGURE 7.2-2. Condensor Performance Logic Tree

The logic flow for this series of tests is shown in Figure 7.2-3.

The blocks in both logic trees can be interpreted as involving only a comparison of the current values with fixed limits. This simple interpretation provides low confidence in the conclusions, 30 to 50%, since the tower water sub-system can be in a transient state at the time the data is sampled. In order to achieve acceptable confidence levels, the evaluations must be based on both instantaneous (to detect catastrophic problems) and smoothed or averaged data to capture accumulative degradation.

Examining this set of monitoring concepts in terms of the requirements established in previous paragraphs, the same general conclusions arrived at apply. In this sub-system, it is important to examine specifics. The specifics are:

a. The condensor has an open and inspect PM action. The inspection is directed toward detecting fouling, erosion, and other forms of mechanical failure.

b. The flow regulator valve has an open and inspect PM action. The action is directed towards identifying wear and damage on certain parts which are replaceable items.

c. The pressure regulator has an open and inspect PM action of the same nature as the Flow regulator.

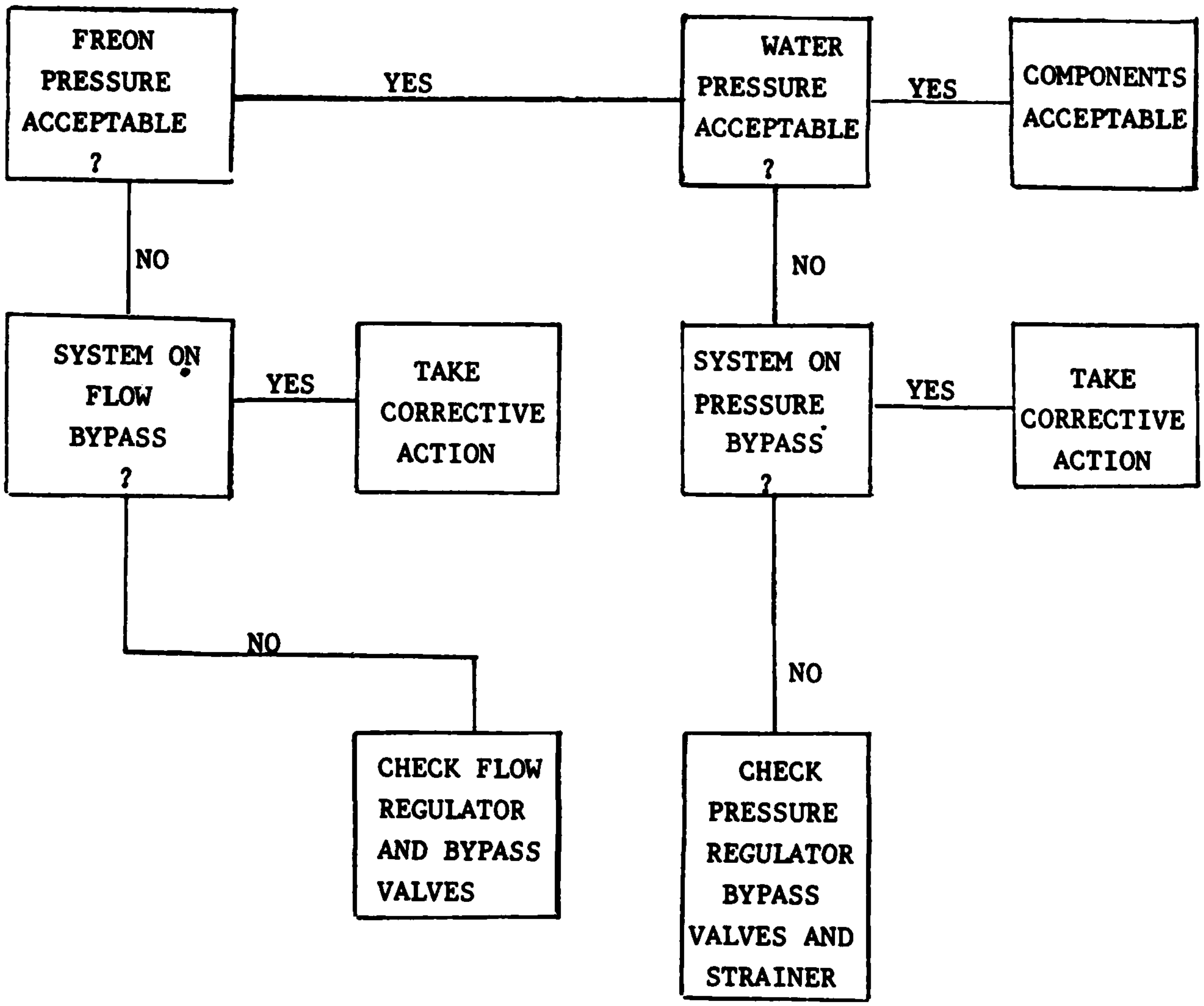

FIGURE 7.2-3. Water Component Logic Tree

Examining the three actions in terms of the data provides the following information:

a. The degree and rate of fouling on the condensor is known - No inspection is required.

b. The flow conditions over the history of the condensor are well identified. Since flow variations are the major mechanism involved in erosion and internal mechanical damage, the period between inspections can be changed to: "as required". The requirement is based on allowing the flow to remain out of tolerance for a period of time.

c. The repairs to the regulator valves require parts replacement. The failure of a regulator valve does not render the sub-system inoperative, it reduces the capability during repairs. The inspection of these components can be put on an "as required" based. The requirement would be based on a monitor indicated problem.

7.2.3 Electrical and Control Subsystem

This subsystem has three functions:

a. Convert electrical power into mechanical power.
b. Control system performance to meet ambient load demands.
c. Provide protection for the system if certain major failures occur.

The first of these functions is performed by the motor. The various failure modes for motors were discussed in Section 6.4.2. The mechanisms contributing to these failures include:

a. breakdown of insulation resistance.

b. mechanical failures in winding.

c. bearing failures both due to wear and due to induced vibrations.

One method of evaluating motor performance and condition is to compare the electrical power input to the temperature rise in the motor, referenced to ambient temperature. Major excursions on electrical characteristics including opens and shorts are readily observable.

Bearing problems may be detected by vibration and acoustic techniques, particularly in a simple machine having only two bearings. These techniques are strengthened by comparison with past performance and long term trend analysis. Finally, the availability of a second machine for comparison purposes strengthens the technique even further.

The control function presents a unique problem in monitoring, as it does in the present maintenance situation. The control function is basically a set of logical conclusions -- when a given set of temperature and pressure conditions occur, a specified change in system operation is implemented. The degradation modes within the

control system are almost wholly component degradation rather than functional degradation.

Direct measurements of the degrading components is nearly impossible without interfering with system operation. Further, since the components are two-state devices, the probability of catching one of them in transition (either with a machine or an operator) is very low during system operation.

The above problems can be solved, to some extent, if the monitor has the capability to correlate data collected in the other subsystem with the current condition of the system. For instance, the system can go into a short term start/stop cycle, if the high and low suction pressure switches are miss-set. Extension of this to its extreme, results in a destructive oscillatory condition. An overwide spread of these same switch settings, results in the compressor running continually, even during reduced loads.

Either of these conditions can be deduced from knowledge of the compressor duty cycle, system load, and the temperature/pressures existing at certain points. The portion of the problem not adequately dealt with is defining the adequacy or degree of correctness for the function.

The maintenance manual defines a procedure for testing and adjustment of the control system. Execution of this procedure with the monitor in a continuous sense mode, i.e., operating as a tester, will greatly reduce the difficulty of this task and provide the data for more

optimum adjustment of the subsystem. The safety interlocks are tested during this sequence.

Adding a minimal number of electrical test points allows an excellent diagnostic sequence to be developed which can identify a fault by comparison with other system parameters down to one or two components in the control subsystem. This diagnostic generally would be functional only during the test sequence.

The logic flow for this monitor and test sequence is shown in Figure 7.2-4.

7.2.4 Chilled Water Subsystem

The primary functions of this subsystem are:

a. Supply chilled water to the remote loads.

b. Transfer the heat picked up in the remote loads to the Freon.

The supply is provided by the chilled water pump. This pump suffers three types of degradation: loss of capacity due to wear, gland leakage, and motor failure. The motor failures are almost completely due to water damage.

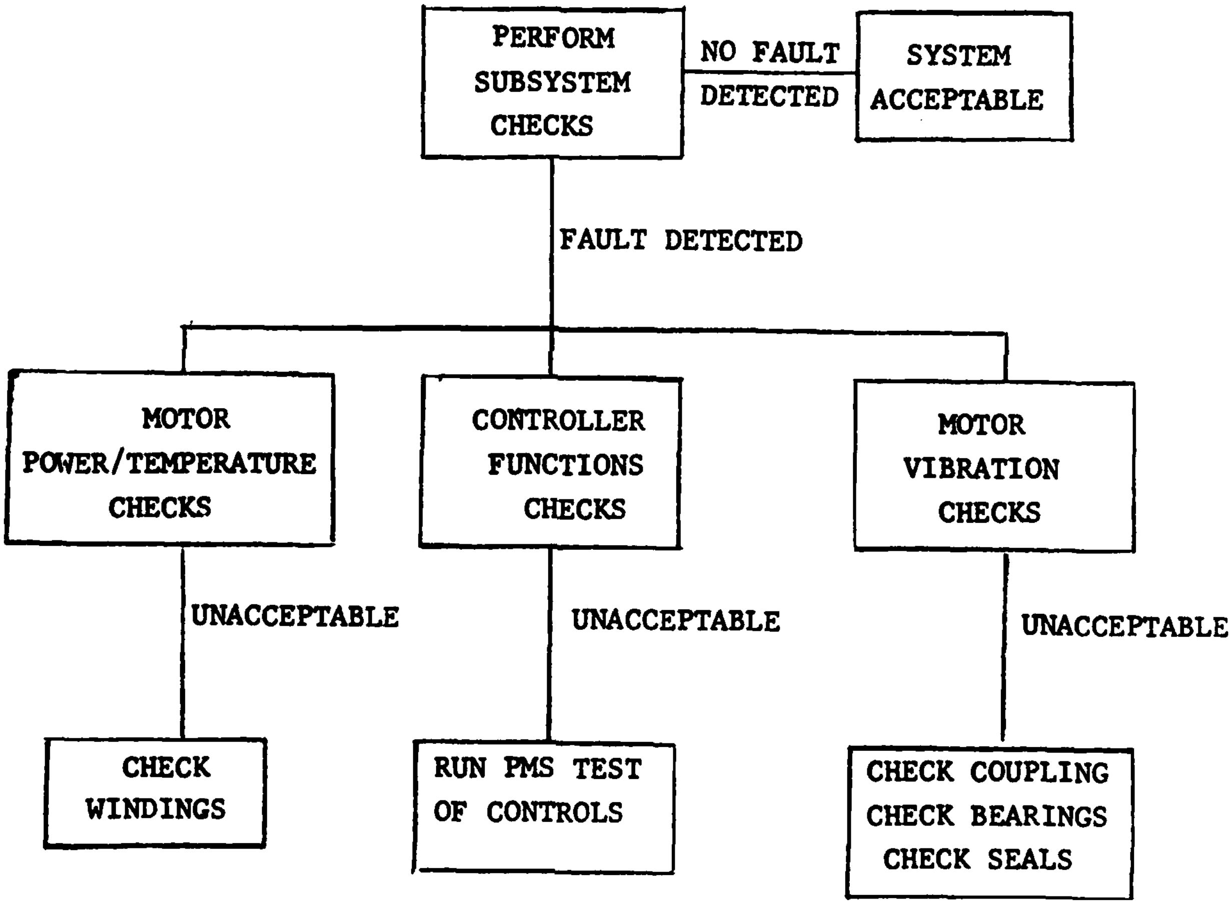

FIGURE 7.2-4. Electrical and Control Subsystem Logic Tree

Heat transfer is accomplished in the chiller. The mechanisms directly affecting performance are:

a. Fouling of the chiller either on the Freon or the water side.
b. Malfunction of the control sub-system, in particular: the expansion valve or the suction pressure switches.
c. Shortage of Freon in the system.

The data required for evaluation of these functions includes:

a. Return water temperature.
b. Chilled water temperature.
c. Freon temperature and pressure.
d. Water mass flow rate.
e. Freon flow rate.
f. Chilled water main pressure and temperature.
g. Design constants for components.

This data generally coincides with that currently available on the installed instruments or provided in the maintenance manual. The Freon mass flow rate is not currently instrumented. A method has been developed for using the chiller as a laminar flow meter. The method is not so well defined as that for the condensor, due to the existance in the chiller of both liquid and gaseous Freon. For purpose of the following discussion, it is assumed that an adequate means of measuring Freon mass flow is included in the monitor.

The most straight forward approach to evaluation of this subsystem requires that a system level judgment be made, based on tests at the plant level, followed by a series of tests of the components in the subsystem. This is accomplished by first calculating the total refrigeration load on the chiller. If it exceeds the rated load, check against other chillers for additional capability and recommend balancing between plants or reduction of the load as applicable.

If the load is less than 600 tons, check the water pressure. Due to the variability of tne load, the pump has a pressure regulating by-pass which maintains constant pressure.

The pressure test with this mechanization does not fully define the condition of the pump. The PM provides an open and inspect action to determine pump wear. The period between inspections can be extended by a periodic test which forces the pump to work at its rated capacity. In the current configuration, this test does not interfere with the normal operation of the system, since the chillers can be cross-coupled into either pump with built-in valving. The test would require perhaps 15 minutes, as compared to two hours for the open-and-inspect action. Further, the test could be scheduled on an "as required" basis, since plants operating with full air conditioning load will provide adequate data in routine monitoring.

The chiller condition can be determined by: measuring the rate of heat transfer, determining the temperatures driving this heat transfer, and calculating a figure of merit for the device. A trend record for the chiller will adequately define the degree of fouling,

as well as the rate at which it is occurring. This data can change the PM "open and inspect" action, from a scheduled action, to an "as required" action. This point is justified by the existence within the monitor data of a record of flow and pressure conditions which could induce fatigue.

Figure 7.2-5 is a simplified logic flow for this series of tests.

7.2.5 Compressor

The function of this component is to raise the temperature of the Freon gas coming from the chiller to a temperature high enough that heat will be transferred to the tower water in the condensor.

Its capability to perform this function can be determined at any time by setting up a power balance equation for the machine. The mass flow rate of Freon is known from the chilled water system. The electrical power input is known from the motor measurements. The losses can be derived from knowledge of the ambient conditions and historical trend data for the particular installation. The rate at which the machine is doing work is defined by the pressure rise from intake to discharge, the gas composition, and the mass flow rate. Within the limits of instrument error, this power balance compared with performance specifications provides a good measure of performance. When compared with historical data for the particular machine, it gives a better means of determining performance and provides reasonable insight into machine deteriorations.

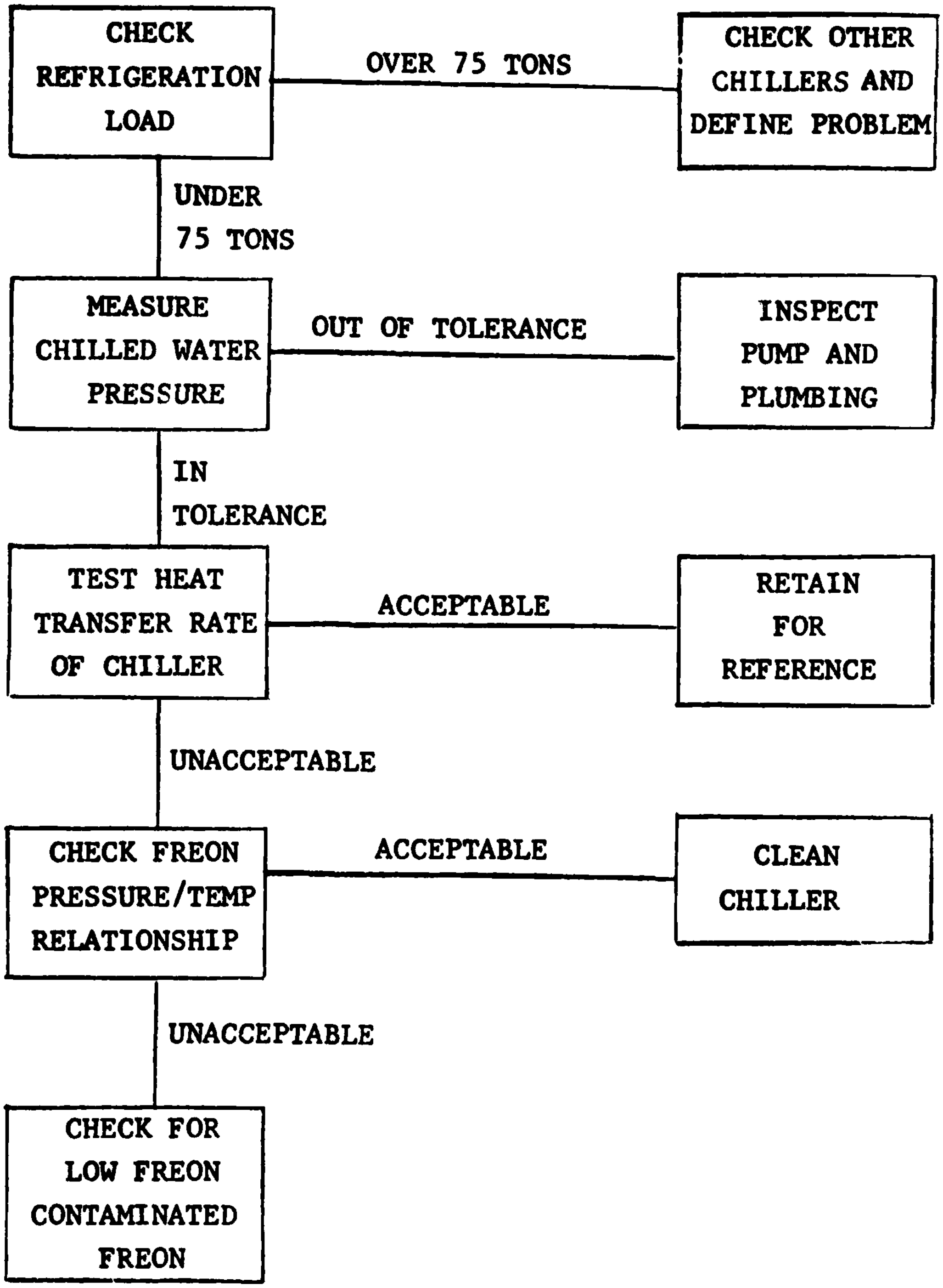

FIGURE 7.2-5. Chilled Water Subsystem Logic Flow

The power balance data deals only with the top of the machine - plus the mechanical integrity of the gasketry associated with the top of the machine. The bearings, lube oil system, shaft seals and lower gasketry are not monitored. It is assumed that a catastrophic fracture failure in these components (or in the top cylinder components) will register either by a change in performance, up to and including a complete loss of performance, or by vibration which can be sensed by a simple vibration monitor. This leaves the gradual failure by wear mechanisms, including accelerated wear due to contaminants and/or induced vibrations.

Manufacturers data indicates that the bearings are among the most reliable components in the compressors if failure inducing mechanisms are controlled. A monitor concept based on these conclusions is defined in the following paragraph.

Monitoring of the lubricating oil pressure and temperature provides data on this particular function on which maintenance actions can be planned. In addition, operation with these parameters out of tolerance decreases bearing life. A historical record of such deviations provides some prognostic information about bearing life and the requirement for inspection. A vibration probe which senses vibrations induced by misalignment of the motor and compressor will provide a degree of prognosis, since this vibration will shorten both bearing and seal life. Finally, a detailed knowledge of the degree of contamination in the system provided by the moisture monitor, and the knowledge of the Freon temperature/pressure characteristics, provide further basis for deducing bearing condition.

Figure 7.2-6 is a simplified logic flow for the compressor tests.

7.2.6 Air Condition System Monitor Concept

The preceeding paragraphs have dealt with a series of sub-system monitoring concepts. These concepts involve a successive evaluation of the performance of the various subsystems. Since the sub-systems are a part of a closed system loop, the evaluation within a particular subsystem requires knowledge of the performance of the other subsystems. Further, since a very desirable capability is prognosis, a degree of prognosis is achieved through the use of historical trend data developed by the monitor. This data also strengthens subsystem evaluation, since the monitor is able to evaluate the performance, both against specification standards and specific machine performance standards. The latter standards allow earlier detection of degradation. In addition to evaluation of the subsystem, the monitor will provide a reasonable level of fault-isolation within the subsystem. No additional requirements are believed to exist at the system level. The reporting at this level is defined in paragraph 7.1.4.

7.2.7 Diesel Generator Monitor Concept

The generator is a transducer which transforms the motion of the diesel crankshaft into on electrical output. Fourier analysis of the generator output could reveal cylinder misfire, loss of compression, etc., by detecting variations in the instantaneous angular velocity.

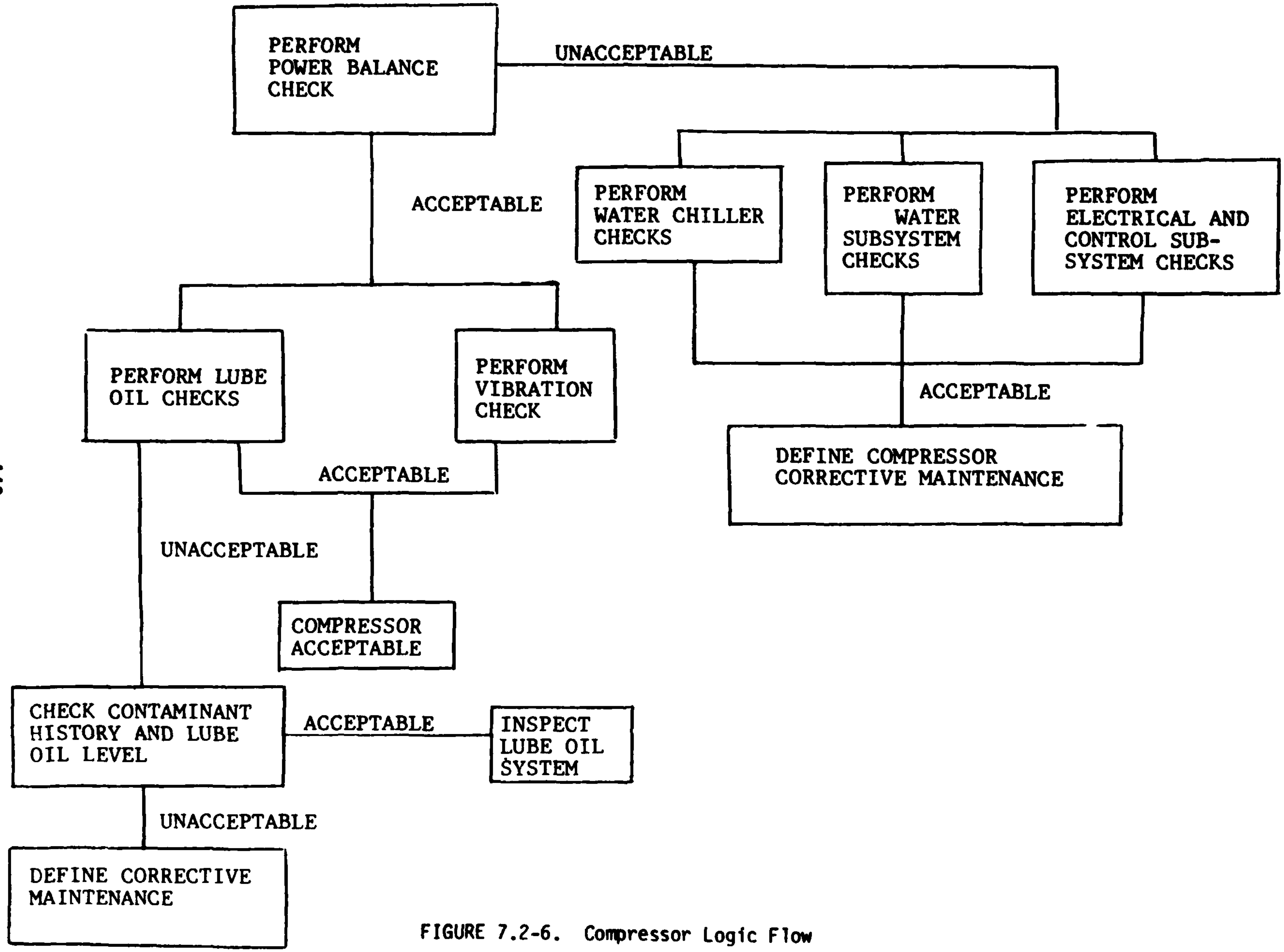

FIGURE 7.2-6. Compressor Logic Flow

The most important performance measure, however, is the quality of the generated power. Monitoring gives a measure of confidence in real time that the quality of power is adequate when the plant is operating properly. Trend analysis of the readings should reveal gradual degradation that can be corrected before problems are compounded. Specific fuel consumption is a measure of diesel performance that lends itself to trend analysis and in fault isolation to distinguish between problems with the diesel and instrumentation problems.

7.2.8 Monitor Concept Summary

A. The monitor concept as developed in this section requires a mechanization which can perform the following prime functions.

1. Data collection
2. Data storage
3. Data reduction
4. Display of maintenance specific data
5. Corrolation of readings
6. Trend Analysis

B. These functions must be accomplished in a manner which will be conducive to improved performance of the power and air conditioning and compatible with the projected manning and skills at the organizational maintenance echelon.

C. The concept provides for change in the scheduling for major PM "open and inspect" component actions.

D. The concept provides for using the monitor as a test evaluation tool during alignment and/or evaluation of the system. In this mode, the monitor can measurably improve the result of these actions by reducing number of subjective conclusions drawn by the operator.

E. The concept provides the CEMIRT and Depot with the required tools and data to aid in planning repair actions and evaluating the results of repair actions.

F. The concept, since it requires data storage and processing of data, can provide as a secondary function, computer compatible performance data.

7.3 Parameter and Sensor Definition

The previous sections of this chapter have defined the requirements imposed on a monitor system, and then developed a monitoring concept, based on these requirements and the characteristics of the power and air conditioning system.

The concepts developed specify generic functions such as data collection and data reduction. They also specify generic classes of data such as temperature, pressure and vibration. These generic functions and data must be expanded upon further to specify the

type and number of sensors and the equipment required to perform all other functions.

The reliability and maintainability of the model should then be evaluated, along with the impact of this system on the various maintenance levels.

7.3.1 Parameters

Applicable parameters are very extensive and there is great diversity of equipment types.

To achieve the study objectives, the data base of test and monitoring requirements was structured by cataloging all of the test/diagnostic measurement parameters applicable to condition monitoring. These parameters comprise a set sufficiently large to warrant careful selection of subsets in calling out parameter values and in specifying measurement needs.

Table 7.3.1-1 lists the candidate test/diagnostic measurement parameters.

TABLE 7.3.1-1. TYPICAL TEST/DIAGNOSTIC MEASUREMENT PARAMETERS

- Time
- Temperature
- Pressure
- Displacement
- Velocity (speed, linear, angular)
- Acceleration
- Flow
- Voltage
- Current
- Power
- Harmonic Distortion
- Power Factor
- *Rotary Speed*
- Resistance
- Impedance
- Torque
- Position
- run down time
- Volume
- Velocity
- Force
- Moisture
- Humidity
- Vibration Power Spectral Density
- Chip Presence
- Thermal Signature
- Ultrasonic Signature
- Liquid Density
- Sludge Density
- Contamination %
- Corrosion Thickness
- Gas Concentration
- Opacity
- Leak Rate
- Partial Pressure

TABLE 7.3.1-1. TYPICAL TEST/DIAGNOSTIC MEASUREMENT PARAMETERS (Continued)

- charge rate
- % Content of Combustion Products
- Position (Contact Closures)
- Wear Thickness
- Acoustic Signature
- Liquid Level
- Thermal Conductivity
- Smoke Opacity
- Particle Mass
- Particle Size Distribution

- Duty Cycle
- Mass
- Elapsed Time
- Contact Closure
- Fuel/Oil Consumption Rate
- Wear Metal Concentration
- Combustion Products Concentration
- leak rate
- height
- depth
- capacity/volume

7.3.1.1 Methodology for Identifying Critical Equipment Parameters

A formal methodology, complete with logic diagrams and rationale, normally would be developed prior to commencement of the analysis to identify what critical parameters to monitor.

First, one would develop a fault tree for each equipment, compare the failure history with the theoretical failure modes and identify the parameters affected by application of physical laws and engineering analysis. A logic is thus established in advance in the form of a decision tree, which selects the minimum number of parameters that cover the failures identified. These parameters are then compared to the state-of-the-art in parameter monitoring. A similar matchup of monitoring techniques is performed using the failure type and component designation. Trade offs between failure mode analysis and parameter types consider the AF environment to ensure the most appropriate techniques emerge. If no existing method exists or difficulties with the existing methods can be identified, recommendations are made to correct the deficiencies. Techniques that need to be developed are defined. At the same time, if the investigation concludes that condition monitoring is not appropriate to some cases, other methods are reported and analyzed for their potential.

7.3.1.2. Matchup of the Test/Monitoring Requirements with the State-of-the-Art Capabilities

The failure detection, diagnostic and prognostic parameters for candidate equipment selected for condition monitoring requirements analysis and technique development have been matched with the state-of-the-art sensor and data processing most favorable for use in the AF environment. The PAVE PAWS environment is rather benign compared to most tactical applications for which there would be further constraints on the selection of sensors.

It has often been stated that electromechanical equipment does not fail gracefully, and that, therefore the bathtub curve doesn't hold water. This is particularly evident in the harsh military environment, where the equipment fails many times before it actually wears out. Exposure to elements such as dust, wind, rain, fungus, insects, smog and corrosive chemicals, along with misapplication, misuse, abuse, design deficiencies, faulty installation, insufficient capacity, etc., are high contributors to failure, but maintenance induced failures seem to be the most frequent cause of unscheduled downtime. It is important that the condition monitoring techniques/ mechanization, not contribute to these problems. On the other hand it must be recognized that certain problems must be corrected, such as design deficiencies, for condition monitoring to be effective. Corrective maintenance, triggered-or-not by condition monitoring, can only restore the equipment to its original designed-in performance

and reliability. If the equipment fails because of poor installation or faulty design, the deficiencies must be corrected for the failure frequency to decline.

A diesel engine that starts consuming its own lube oil does not fail gracefully, it self-destructs unless it is denied air almost instantly. Other failures cause a chain reaction that leads to catastrophic failure such as moisture in the refrigerant system of an air condition reciprocating compressor.

In the diesel case a lube oil pressure monitor will act too late, where perhaps a liquid level switch would shut the diesel down in time. In the air conditioning refrigerant system a solid state moisture sensor might be the single best sensor to monitor. Unless committed to using vibration monitoring, ferrography, spectrographic oil analysis or some other method, only an intense detailed engineering analysis of all the alternatives will provide the optimum technique.

7.3.2 Candidate Air Conditioning Parameters

These parameters, together with the rationale for sensing the parameters, are presented in table 7.3.2-1. The sensors required, together with installation locations, are provided in table 7.3.2-2.

TABLE 7.3.2-1. SENSED PARAMETERS

PARAMETER	REQUIRED FOR	PRESENT INSTRUMENTATION
Freon Suction Temperature	Chiller Performance Compressor Performance Freon Contamination Controller diagnosis	Thermometer
Freon Discharge Temperature	Compressor Performance Condenser Performance Freon Contamination	Thermometer
Tower Water Inlet Temperature	Condenser Performance	Thermometer
Tower Water Discharge Temperature	Condenser Performance	None
Return Fresh Water Temperature	Total Heat Load Chiller Performance	Thermometer
Chiller Output Temperature	Total Heat Load Chiller Performance	Thermometer
Lube Oil Temperature	Compressor Diagnostic Lube Oil Condition Bearing Prognosis	Thermometer
Motor Winding Temperature	Motor Performance Motor Diagnostic	None
Local Ambient Temperature	Motor Performance Motor Diagnostic Compressor Performance Chiller Performance	Thermometer

TABLE 7.3.2-1. SENSED PARAMETERS (Continued)

PARAMETER	REQUIRED FOR	PRESENT INSTRUMENTATION
Freon Suction Pressure	Controller Performance Compressor Performance Freon Contamination	Gauge
Freon Discharge Pressure	Flow Regulator Valve Performance Condensor Performance Compressor Performance Freon Contamination	Gauge
Tower Water Pressure	Pressure Regulator Valve Performance Water Pump Performance	Gauge
Condensor Differential Water Pressure	Condensor Performance Condensor Fouling Water Flow Flow Regulator Valve Performance Condensor Prognosis	None
Chilled Watermain Pressure	Chilled Water Pump Performance Chilled Water System Diagnosis	Gauge
Chilled Water Venturi Differential Pressure	Chiller Performance Chilled Water Pump Performance Total Heat Load	Gauge

TABLE 7.3.2-1. SENSED PARAMETERS (Continued)

PARAMETER	REQUIRED FOR	PRESENT INSTRUMENTATION
Oil Pressure	Compressor Diagnostic Unloader System Check Lube Oil Condition Bearing Prognosis	Gauge
Freon Moisture	Freon Contamination Condensor Performance Chiller Performance Compressor Performance Failure Diagnosis Failure Prognosis	Sight Glass
Main Motor Vibration	Coupler Alignment Motor Diagnosis Compressor Diagnosis	None
Compressor Vibration	Coupler Alignment Compressor Diagnosis	None
Chilled Water Pump Vibration	Motor and Pump Fault Detection	None
Compressor Duty Cycle	Freon Level Controller Performance Controller Diagnosis Compressor Performance Compressor/Controller Adjustment	None
Wattmeter	Motor Performance Motor Diagnosis Compressor Diagnosis	None

TABLE 7.3.2-1 SENSED PARAMETERS (Continued)

PARAMETER	REQUIRED FOR	PRESENT INSTRUMENTATION
Freon Mass Flow	Total Heat Load Compressor Performance Chiller Performance Chiller Diagnostic	None

TABLE 7.3.2-2. SENSORS

PARAMETER	SENSOR TYPE	INSTALLATION
Freon Suction Temperature	Thermistor 2 per machine	Cement to pipe or install in well
Freon Discharge Temperature	Thermistor 2 per machine	Cement to pipe or install in well
Tower Water Inlet Temperature	Thermistor 1 for present configuration	Install in well
Tower Water Discharge Temperature	Thermistor 1 per condensor	Install in well
Return Fresh Water Temperature	Thermistor 1 for present configuration	Install in well
Chiller Output Temperature	Thermistor 1 per chiller	Install in well
Lube Oil Temperature	Thermistor 1 per machine	Cement to line
Motor Winding Temperature	Thermistor 1 per motor	Cement to winding or pole piece
Local Ambient Temperature	Thermistor 2 for present configuration	Cement to structure
Freon Suction Pressure	Bonded Strain Gauge Pressure Transducer- 1 per system	Tee on present gauge
Freon Discharge Pressure	Bonded Strain Gauge Pressure Transducer - 1 per system	Tee on present gauge

TABLE 7.3.2.2. SENSORS (Continued)

PARAMETER	SENSOR TYPE	INSTALLATION
Tower Water Pressure	Bonded Strain Gauge Pressure Transducer Saltwater compatible Metals - 1 for present configuration	Tee on present gauge
Condensor Differential	Bonded Strain Gauge Pressure Transducer Saltwater compatible, Reference side Bellows Buffered 1 per condensor	Best Installation Not defined
Chilled Watermain Pressure	Bonded Strain Gauge Pressure Transducer - 1 per system	Tee into present gauge
Chiller Water Venturi	Bonded Strain Gauge Pressure Transducer, Reference side Bellows Buffered 1 per venturi	Tee into present gauge
Oil Pressure	Bonded Strain Gauge Pressure Transducer - 1 per system	Tee into present gauge
Freon Moisture	Dew Point Detector 1 per machine	Install in Freon Line
Main Motor Vibration	Accelerometer 1 per machine	Cement to motor frame near shaft

TABLE 7.3.2-2. SENSORS (Continued)

PARAMETER	SENSOR TYPE	INSTALLATION
Compressor Vibration	Accelerometer 1 per machine	Cement to compressor near input shaft
Chilled Water Pump Vibration	Accelerometer 1 per machine	Cement to motor pump end
Compressor Duty Cycle	Accumulative Running Time Meter and event counter 1 per machine	Install in controller
Wattmeter	Two current probes, two voltage probes - one set per machine	Install in controller
Freon Mass Flow	Remote Indicating Liquid Flow Meter or Chiller plus Differential Pressure Transducer 1 per machine	Install in liquid line between receiver and expansion valve

7.3.3 Candidate Diesel Generator Parameters

Table 7.3.3-1 lists candidate parameters for a diagnostic system that would enable a comprehensive and cost effective diesel engine check out.

The first candidate parameters are conventional test parameters that are usually observed in any engine-generator operation for rating the performance and for diagnosing accessories. Eleven of these parameters are normally instrumented on Diesel engine-generator sets The remaining measurements are electrical hook ups to the generator output leads, as well as fuel consumption and blowby flow rates.

TABLE 7.3.3-1. RECOMMENDED DIESEL GENERATOR PERFORMANCE/CONDITION MONITORING:

PARAMETERS	SENSORS
<u>Temperature</u>	
Exhaust ports (pipe plug)	Type K Thermocouple
Exhaust common	Type K Thermocouple
Oil before engine oil gallery	Type J Thermocouple
Oil cooling line	Type J Thermocouple
Fuel supply line	Type J Thermocouple
Fuel return line	Type J Thermocouple
Oil return line	Type J Thermocouple
Oil sump	Type J Thermocouple
Intake manifold	Type J Thermocouple

TABLE 7.3.3-1. RECOMMENDED DIESEL GENERATOR PERFORMANCE/CONDITION MONITORING: (Continued)

PARAMETERS	SENSORS
Pressure	
Ambient air	Type J Thermocouple
Intake manifold (after turbo)	Type J Thermocouple
Water supply	Type J Thermocouple
Water return	Type J Thermocouple
Bearing	Type J Thermocouple
Cylinder	Gauge Transducer
Engine oil galleries	Gauge Transducer
Engine oil	Gauge Transducer
Ambient pressure	Absolute Transducer
Injection pump	Gauge Transducer
Fuel pump	Gauge Transducer
Turbocharger	Absolute Transducer
Water supply	Gauge Transducer
Crankcase	Absolute Transducer
Exhaust back pressure	Gauge Transducer
Inter cooler water	Gauge Transducer
Air inlet	Gauge Transducer
Vibration	
Rocker box (valve) cover	Accelerometer
Engine block vibration	Accelerometer

TABLE 7.3.3-1. RECOMMENDED DIESEL GENERATOR PERFORMANCE/CONDITION MONITORING: (Continued)

PARAMETERS	SENSORS
Flows	
Fuel supply line	Turbine Flowmeter
Fuel return line	Turbine Flowmeter
Blowby (breathing system)	Pressure transducer
Engine oil	Weight Scales
Air-intake (supercharger)	Turbine flowmeter
Position	
Crankshaft ^{o}CA	Timing Ref Mark/Proximity Detector
Fuel rack	Linear Transformer
Top dead center	Proximity Detector
Other	
Speed	Proximity Detector
Engine oil viscosity	Viscosity Meter
Exhaust smoke opacity percent	PHS Smoke Meter
Relative humidity	Solid State Psychrometer
Wear metals analysis	ARC-Emissions
Oil debris	Ferrography
Oil particle size distribution	Chip Detector
Fuel moisute content (PPM)	Aluminum/Aluminum Oxide Detector

TABLE 7.3.3-1. RECOMMENDED DIESEL GENERATOR PERFORMANCE/CONDITION MONITORING (Continued)

PARAMETERS	SENSORS
Piston ring wear detector	Proximity Detector
Generator Output Power	Solid State Sensor
Generator Output Frequency	Transformer
Generator Bearing Temp	Type J Thermocouple
Generator Field Current	Shunt
Generator Armature Resistance	Wheatstone Bridge
Insulation Resistance	Megohmmeter
Generator Overheating	Organic Materials Core Monitor (ion chamber)
Winding Temperature	Type J Thermocouple
Instantaneous Crankshaft Angular Velocity	Detects low power in a particular cylinder or misfires
Forced Vibration - Response of Engine Clearances	Bearing clearances
Ultrasonics Boiling Probe	Detects moderate or extreme boiling of water jackets, i.e., hot spots i.e., hot spots

TABLE 7.3.3-2. CALCULATED PERFORMANCE/CONDITION MEASURES

- Specific fuel consumption
- Brake horsepower
- Frequency stability
- Coolant temperature rise
- Fuel dilution of lube oil
- Fuel temperature rise
- Blower pressure rise
- Correction of measured parameters to standard reference conditions
- Power fluctuations
- Turbocharger efficiencies
- Crankcase Blowby Flow Rate
- Wear condition of rings, liners pistons, liners
- Oil consumption rate
- Cylinder performance (comparison)
- Blower performance
- Turbocharger performance
- Lube system performance
- Reference condition for test date, and oil cooler performance
- Cooling system performance
- Intercooler temperature
- Water pump condition
- Overall efficiency, performance

TABLE 7.3.3-2. CALCULATED PERFORMANCE/CONDITION MEASURES (Continued)

- Speed/instantaneous velocity
- Generator friction
- Condition of field
- Condition of armature windings
- Condition of field windings
- Condition of windings at load

Engine fuel consumption has been measured using many different transducer approaches. The significant diesel fuel consumption measurement is differential fuel flow rate. The amount of fuel returned to the tank is measured and subtracted from the total fuel supplied to the engine. Three different type transducers have been used satisfactorily for this task. The engine crankcase blowby flow rate is a good indicator of piston-ring and liner assembly sealing integrity and generally correlates directly with fuel consumption. Blowby flow rate can be measured using a differential pressure transducer across calibrated orifice plates sized to accommodate a range of gas flows from normal to extreme wear conditions.

Special diesel engine tests have been developed to enhance the diagnostic sensor data. These tests enable detection and isolation of faults that are normally difficult to detect using only performance factors. The diesel engine-generator set is particularly adaptable to special diagnostic tests since it resembles an engine-dynamometer test set up. Table 7.3.3-3 illustrates typical tests that can be performed and what value each of these would be in isolating defects

TABLE 7.3.3-3

Test No.	Test Description	Will Determine
1	Steady state operation, (constant speed, constant load)	Overall diesel efficiency, blower and pump outputs, cooling condition, governor regulation, diesel misfires
2	Step electrical load (positive or negative)	Voltage regulation, governor recovery characteristics
3	Crank to start with fuel deliberately off	Individual cylinder compression
4	Run steady state no load on generator	Performance range of pumps, blowers, generator and regulator
5	Run steady state with partial generator load	Performance range of pumps, blowers, generator and regulator
6	Static-engine condition, (zero speed, zero load)	Bearing clearances

and determining engine and generator performance. Note that most of the useful data is obtained when the generator is at normal operating speeds and loads. Special tests such as the step increase in electrical loading (test 2) are used to stimulate the system in such a way as to rate the engine governor and generator voltage regulator control system. Other special tests involve cranking the engine at

low speed with the engine starter in order to examine the compression characteristics of each cylinder of the engine. Also some of the data is obtained at static conditions of zero speed. These candidate tests represent a way of expanding the utility of the sensor data to reduce the number of sensors required in the final diagnostic system.

Three candidate diagnostic parameters are discussed separately in the following paragraphs due to their experimental nature. These parameters are explored on the basis of their ability to enhance the overall diagnostic capability provided by the conventional parameters listed previously.

1) Instantaneous Crankshaft Angular Velocity is defined as the change in crankshaft speed due to the specific torque.inputs from the individual engine cylinders. During cranking tests, the crankshaft speed responds to the compressed gas loads in each cylinder. The integrity of the compression seal in each cylinder can be evaluated individually by measuring the corresponding magnitude of the crankshaft speed change. The combustion integrity of each individual cylinder can also be evaluated by measuring the magnitude of the crankshaft speed changes with the engine running. The combustion integrity is directly related to both compression (previously evaluated in the cranking test) and the fuel injection characteristics.

This technique has been demonstrated and used successfully in diagnostic systems before. The crankshaft accelerations were measured by accurately measuring the flywheel speed by counting the flywheel

ring gear teeth, using special transducers and electronic circuitry designed for that purpose. The same speed information can be obtained by analyzing the generator output frequency for the speed variations caused by the individual cylinder power contributions. Experimentation along this line has been performed at SwRI and has indicated that the approach is valid but requires electronic system development work. This technique would allow rapid diagnosis of compression and fuel injection faults using a simple electrical hookup to the generator.

2) Forced Vibration-Response. This diagnostic technique is common in field diagnostics involving all types of large stationary rotating machinery such as pumps, fans, and turbines. The technique differs significantly from the classical vibration signature analysis approach used in the past. The forced-vibration technique involves shaking or impacting the engine with a known vibration when the engine is at rest. The vibrational response is measured, recorded and analyzed. The technique is superior in that the forcing function is determined and known by the diagnostician who is measuring the vibrational response. Bearing clearances can be determined using this technique. It is proposed that this technique should be explored for its diagnostic value by first determining the crankshaft dimensions and weights and bearing clearances for the engine and using them in a mathematical model of the engine crankshaft vibrational modes. Typical worn bearing clearances (usually in excess of 0.001 inch per inch of bearing diameter) can be used to check the feasibility of this approach in determining the onset of bearing wear and for distortion. The magnitude of the required forcing function can also

be determined using the mathematical model. This procedure is reported to have been performed several times by SwRI on numerous types of machines. If the computer simulation indicates the technique is feasible then tests should be conducted using electrodynamic shakers and accelerometers clamped to the external crankshaft components.

The feasibility of using this technique on shafts of turbochargers, blowers and camshafts needs to be explored. Data analysis programs must then be developed to integrate this technique into the diagnostic system.

3) Ultrasonic Boiling Probe. A proprietary transducer has been developed at SwRI that can indicate the relative rate of surface boiling. The sensor has been tried out in bench tests, set up to simulate boiling on cylinder heads and liners. The sensor is placed on the outside of the engine and can detect the formation and breakaway of steam bubbles on a surface while looking through the water jacket material and the coolant liquid. It is proposed that a study be conducted to locate spots on the engine heads and cylinder liners that have the highest heat flux. These locations will become early hot spots in the event of over heating and will be the place where boiling will take place first. As a result, these locations will also be where scale will form first and as a consequence will be detectable at high engine loads as boiling locations. The study should also include some development of sensor surface adaptors to enable easy positioning of the probe during engine operation. The use of this probe during full load shakedown tests will enable the

diagnosticians to assess the location and magnitude of cooling system scale formation. A data analysis program would allow simple indication of excessive boiling rate based upon the results of the study and exploratory tests using the engine-generator.

7.4 HARDWARE DESCRIPTION

The basic hardware for the performance/condition monitor consists of a configuration of transducers connected to the processing and diagnostic hardware. A simplified block diagram of the hardware is shown in Figure 7.4-1.

The Input Data Multiplexer enables the processing of a sequence of transduced differential voltage signals with a single signal processing channel.

The signals as measured by transducers are electrically processed to develop a signature. Under program control, the time of data sampling is synchronized to specific events during each rotating equipment cycle.

The transduced temperature and pressure voltages are converted to a digital equivalent prior to final data processing and eventual storage. This selected transduced parameter is amplified for a common analog to digital conversion with the gain set so that the largest anticipated signal is equal to or less than the full scale range of the A/D converter. The initial signal data processing must be fully

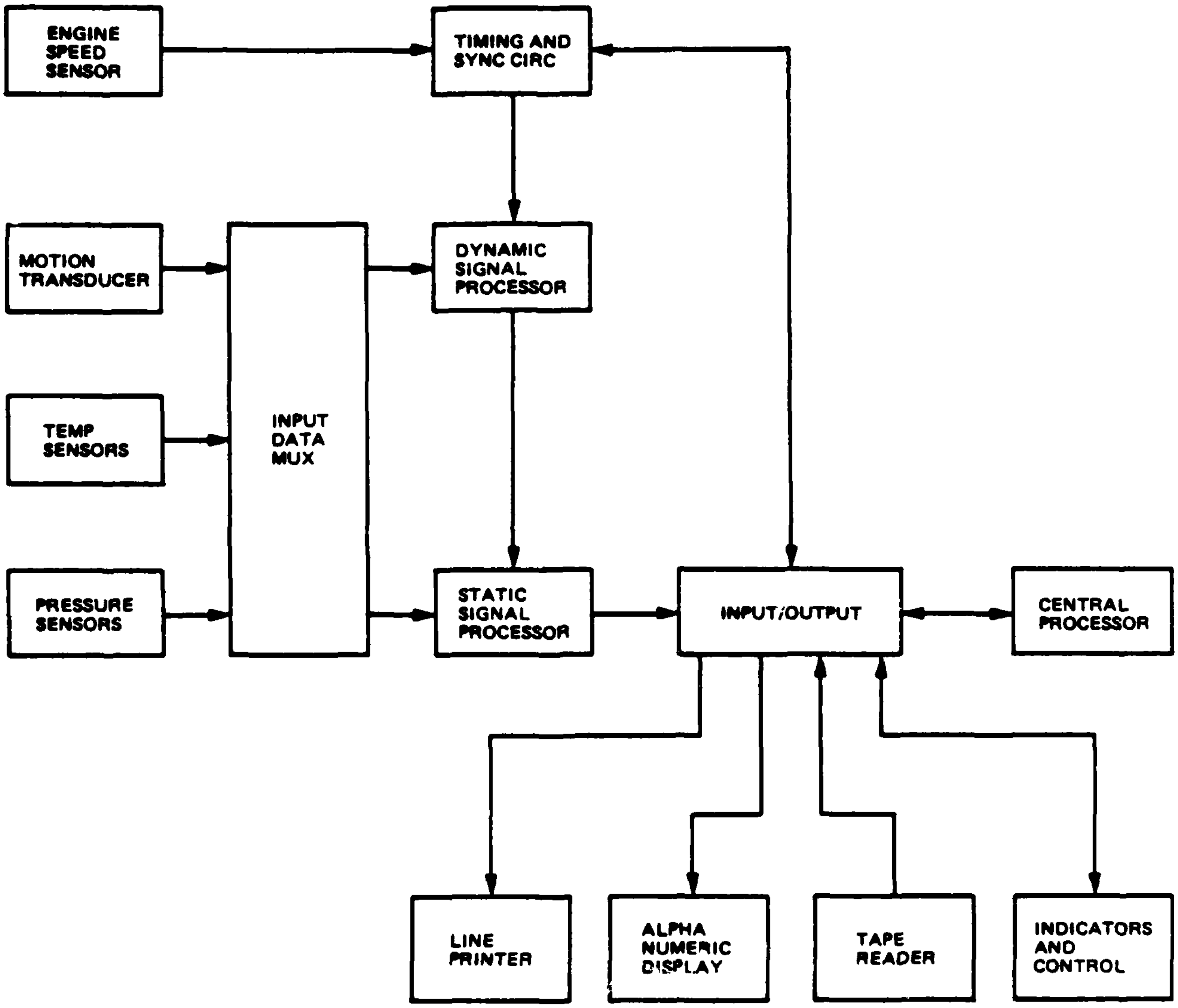

FIGURE 7.4-1. Integrated Diesel Engine Monitor (Simplified Block Diagram).

adaptive such that it compensates for any voltage offset or drift due to changes in environmental conditions or timing. The signal processing compares relative rather than absolute values.

Each transduced voltage output must be sampled programmably and its processed digital equivalent stored for subsequent processing.

7.4.1 Sensor Characteristics

Many sensors are available in two configurations:

a. A basic probe with signal output levels of a few millivolts.

b. The probe with signal conditioning equipment and output levels in the 5 volt range.

The sensors are mounted on or near the machines. This environment is severe and electronic failure rates in the signal conditioning circuits could be excessive. Examination of the sensor list shows that the majority of the sensors require the same type of signal conditioning, allowing a single signal conditioning circuit to handle several sensors.

The potential increase in reliability and a reduction in hardware costs define configuration (a) as the most desirable. If signal-to-noise problems occur, individual sensors can be buffered.

7.4.2 General Electronics

The machinery spaces where the current machines are located can become a severe environment for electronics equipment should the temperature in this area remain in the 40^{o} to $50^{o}C$ range for extended periods. While electronic equipment can operate in such an environment, the stress levels are high and the reliability decreases.

A major cost item in any system is the cost of cabling. The low level sensor signals defined in the previous paragraph generally require special cabling and are not compatible with long cables. A common solution to this problem is to collect these signals at a central location, multiplex these signals into a signal conditioner, and convert them to a serial digital data train for transmission. The data transmission is not critical, particularly at low data rates such as those required for the monitor. This method reduces to a minimum the electronics in the severe environment and reduces the number and criticality of the cables.

The configuration for this monitor system should be modular, containing the minimum electronics required for the function. The modules should be equipped with quick-disconnect connectors for easy change-out. Sufficient built-in test capability should be included to provide high assurance of fault isolation to this unit. The MTBF of the unit should be on the order of 10,000 hours for production hardware.

7.4.3 Data Processing

The requirement for data processing has been established in a logical progression from user requirements to functional requirements and to monitor concepts. The method of implementing this function and the location of the equipment follows. This section of the report presents the data processing requirements and defines a set of equipment meeting these requirements.

7.4.3.1 Data Processing Requirements

The data processing task resolves to the solution of a single problem: "Is the power and air conditioning equipment performing acceptably?" If the answer is no, the general solution data must be examined to determine which part of the solution has a fault. Then the data must be compared with other parts of the solution and with stored data to determine where the equipment failure lies. This is accomplished by sorting through a library and identifying the probable area where corrective action is required. Finally, it must present a simple English Language message, understandable to the user, which results in an appropriate maintenance action.

This is essentially the problem solved for each unit tested by the processors in Automatic Test Equipment. These are generally in the class of digital processors, defined as "mini- or micro-processors". The size and complexity of the required mini-processor is defined by the number of peripheral devices required and the amount of memory required. The peripheral device requirements are:

a. A remote display system.

b. The electronics unit, defined in the last paragraph.

c. A mass storage device for data collection.

d. A printer.

Mini-processors with the capability of handling 30 peripherals are available. The requirement for four peripherals here puts this in the very small processor class.

The memory requirements on the processor are separated into two blocks:

a. An operating system which allows the processor to function.

b. The application program which defines the power and air conditioning monitoring.

The first block can be considered as an overhead function. The second block is the monitor function.

The operators of this system are not required to program it, but only to use and repair it. The programming is then completely transparent to the site. This would allow the program to be stored in machine language -- the most efficient language for storage. Under this assumption the memory requirement is:

Block a	1200 words	16 Bits/word
Block b	8000 words	16 Bits/word

This estimate is based on a comparison of measurements, calculations, decisions, and stored data between the performance/condition monitor and an existing data analysis collection system which handles a similar problem. Allowing for growth during detailed design, a reasonable memory estimate is 10,000 words resident in the processor. This represents a small fraction of the capability of the smaller processors. A processor in this class occupies a less than two (2) cubic feet and has a MTBF better than 12,000 hrs., when adequately protected against shock and vibration and operated in an ambient temperature between 0^{o} and $40^{o}C$.

7.4.3.2 Adaptable Software

The test program sequences required to monitor, test and diagnose the condition of electromechanical equipment must include:

- Closure path via input multiplexer for each relevant sensor.
- Programmable gain prior to A/D conversion for each relevant sensor.
- Normalization data look-up tables; this includes the scale factors for those parameters which are affected by the operational and ambient environment.
- Reference values premised on "normal" performance with upper and lower limits.
- A series of identifiable fault patterns for diagnostics.
- A series of diagnostic messages relevant to the identifiable fault patterns.

- Self check messages.
- Hazard messages.
- Operator action messages.

Adaptive system reference limits can be programmably changed as a consequence of accumulated test history.

- Parameter groups - weighting of measurements with respect to interrelated parameters.
- Printout information such as parameter types unique to a particular engine.

7.4.3.3 Condition Monitoring Data Processing and Displays

PAVE PAWS Facility Management System provides sensor scanning and alarms for out-of-tolerance conditions but has no memory for performing trend analysis, correlating readings or performing other sophisticated computation. The Modcomp Radar Controllers perform both functions to a limited but expandable extent in operating and troubleshooting the RADAR. This means that the FMS/Sensor interfaces and the Modcomp/RCL Display interfaces are well established. Time and budget economies are available if these interfaces are preserved in the condition monitoring implementation. This can be accomplished by tying the FMS to the Modcomp over a data bus to allow the Modcomp to access the sensor readings. The most primitive implementation could be accomplished one way over the teletype line that now drives the printout. This would provide the sensor data to the Modcomp on a non-interference basis, i.e., both systems would virtually operate as

now (i.e. stand alone). One of the penalties in this scheme is speed. The data rate for the printer data line is limited by the mechanical speed of the printer. The next higher level of implementation eliminates the slow data rate by passing the data over a general purpose Input/Output bus. The next tier of sophistication would permit the Modcomp to instruct the FMS to go to a specific sensor or group of sensors. Beyond that could be implemented the ability to command the FMS to control equipment - such as switch fans. The hardware costs to employ any of these schemes is minimal and somewhat independent of the level of sophistication. The software cost escalates with increased sophistication, however, it capitalizes on the fact that the Modcomp is already installed and both the hardware and software are supported. The alternative, upgrading the FMS Honeywell Delta 2000, would incur installation, checkout, and learning curve delays and expenditures that the previous scheme avoids.

7.4.3.4 Hardware/Software Tradeoffs

Condition monitoring of many systems favors minimizing the number of sensors by investing in smart software to permit extracting the maximum performance/condition monitoring information from the least number of sensors. This scheme is favorable to deployed systems to keep down the parts count (maximize reliability), and where skill to troubleshoot and replace parts (including sensors) is at a premium. Large PAVE PAWS-like stationary systems with skilled on-site personnel favor the more traditional approach, to maximize (within

reason) the number of sensors and compare readings to differentiate between a failure in the physical plant and a faulty sensor. The software envisioned for PAVE PAWS Condition Monitoring would solve continuity and conservation of energy equations to give higher detection rates with fewer false alarms.

7.4.4 Display

In normal use the display need not be located at the machine. During test, adjustment or troubleshooting a local display is required. Since the displayed data will be word messages, the most economical device is an adaptation of the current Cathode Ray Tube (CRT) displays used with processors. The optimum configuration would place one display at a location, readily available to the operations and maintenance personnel. A second portable display can be used during test, adjustment and troubleshooting. A plug for this display can be provided in the electronics unit defined earlier.

In addition to this display, there should be a minimal set of indicators on the electronic unit to define on/off and operational condition of the monitor.

7.4.5 Mass Data Storage

One of the requirements at the CEMIRT, the depot and various other organizations is for historical data. This can be met easily by storing the output of the processor in a computer compatible format. Since the site has little or no use for this data, the best

selection for a storage device is a magnetic tape recorder, from which tapes can be shipped directly to the using level. This device should be located with the processor.

7.4.6 Printer

A printer is included to provide hard copy print-out of the data which is presented on the display. It has been assumed that such a print-out will be required to maintain engineering operating logs. This function could become redundant.

The printer is a low-speed character printer like those used for processor terminals. The location of the device is not critical, except that it should not be located in machinery spaces.

7.4.7 Reliability of Monitor

A reliability prediction on the model system defined above is beyond the scope of this effort. Since specific components have not been defined, the data used to generate the prediction for failure rate per 1000 operating hours could initially be based on the averages of the values supplied by several vendors. Estimates for electronics and cables can be based on experience with similar hardware. The printer and magnetic tape recorder can be rated on the basis of a very limited duty cycle compatible with their proposed use. Derating factors should be based on the environment.

7.4.8 Maintainability and Maintenance Concept for the Monitor System

The monitor system model used in this report was developed to comply with the concepts that require adequate equipment performance under conditions of minimum skill level and equipment repair/change-out at the organizational level. These concepts, carried through to the monitor system, impose the following constraints:

a. High confidence in self test.

b. Extensive self diagnosis.

c. Modular packaging.

7.4.8.1 Self Test

Systems of this type inherently have a high level of self-test capability built into the software. This particular monitor system concept has certain added capabilities. These are:

a. Many of the parameters sensed are directly interrelated, allowing the monitor to compare similar data from two or more sources.

b. Much of the data is converted into trends. Any particular data point is evaluated against previous data, and major deviations can be questioned.

AD-A138 576 CONDITION MONITORING TECHNIQUES FOR ELECTROMECHANICAL EQUIPMENT USED IN A..(U) HUGHES AIRCRAFT CO LONG BEACH CA R R HOLDEN AUG 83 RADC-TR-83-180 F30602-81-C-0113

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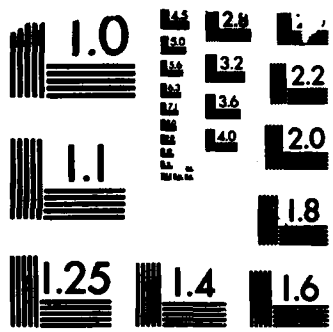

MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS-1963-A

c. The machines under test are redundant, and to some extent crosscoupled, allowing comparisons between data from two comparable sensors. This data is subject to even further cross-coupling, by sharing of certain electronic components.

7.4.8.2 Modular Change-Out

The major assemblies of the monitor should be designed for complete change-out at the organizational echelon. This concept must be adhered-to in order to meet the user requirements defined earlier.

Within the major assemblies which change-out at organizational echelon, there is a second tier of assemblies which can be tested on general purpose ATE and replaced at the Intermediate level. A detailed study of Intermediate level implementation costs is required to determine whether this, or a pass through to the depot, is the most cost effective course.

The depot level has the capability to repair all assemblies and subassemblies. The sensors, due to their nature, may prove to be nonrepairable on a cost basis. A detailed study of implementation costs for sensor repair at the depot is required to define the most cost-effective course.

7.5 TEST AND EVALUATION OF THE MONITOR SYSTEM

This section of the report defines the goals of a test and evaluation program and provides a preliminary plan for such a program. The requirement for evaluation of each aspect of a maintenance plan or concept is clearly established within the program definition.

Project development in all areas will be measured and evaluated by the use of test sites.

7.5.1 Goals

The test program should provide the data to evaluate each of the following elements:

a. Air conditioning/power performance improvements.

b. Air conditioning/diesel generator maintenance improvements.

c. Monitor interface with AF personnel.

d. Monitor interface with CE organization and facilities.

e. Verification and modification of monitor concepts and designs.

7.5.2 Preliminary Plan

Four phases are recommended:

Phase I - A hardware/software design, fabrication and test phase.

Phase II - A contractor support phase for installation and checkout and on-the-job training at the site.

Phase III - An Air Force test and evaluation phase with contractor support at the repair of repairables level.

Phase IV - An Air Force analysis and decision phase which overlaps the final portion of Phase III.

7.5.3 Phase I

The predicted time required for this phase is 12 months. This time span allows for the continuing increase in component procurement lead time. It is possible that this schedule could be improved; however, planning should not be based on this possibility.

In order to adequately support the following phases, it is recommended that two systems be procured. The second system would be used to provide spares support. This recommendation is based on experience in a number of similar test programs. In these programs system reliability has little meaning, due to operator learning curves and induced failures.

7.5.4 Phase II

This phase includes, in addition to installation and checkout, a period of on-the-job training and direct site support. It is recommended that four months be allocated to this Phase.

7.5.5 Phase III

This phase is for data collection. Based on the failure rates and operation hours discussed in earlier sections of this report, a minimum of 18 months is required to collect adequate data. It is possible that this data collection phase could be reduced by the common test program technique of operating at increased stress levels. This technique, when applied to an operational site, could result in reduced capability for performance of missions, other than test and evaluation.

7.5.6 Phase IV

This phase will overlap Phase III, with useful data becoming available in the third, or fourth, month of that phase. The final decisions resulting from this Phase should be available four months after completion of Phase III. One of the important decisions which should be made is that concerning "on-line" versus "off-line" monitoring.

8.0 PRINCIPAL STUDY CONCLUSIONS

- It was possible to develop a condition monitoring system design for PAVE PAWS prime power generation and cooling equipment, utilizing state of the art monitoring tecniques and sensors.

- In the absence of condition monitoring, the vulnerablity to failures in diesel generators, motor generators, and environmental control units constitutes a real threat to C^3I system readiness and availability.

- Along with their growth in sophistication, modern military systems tend to be less tolerant of excursions from the power and environment norms specified in the design.

- The electromechanical equipment is not sufficiently instrumented to produce the engineering data required for characterizing failures or predicting wear out.

- The item managers for electromechanical equipment lack the visibility on how failures in the diesel generators, motor generators, and environmental control units impact specific C^3I missions.

- Still unanswered by PAVE PAWS, ESC, and other sources is the question, "If you were to compare the frequency and downtimes with other causes, where would the combined and

separate causes due to power and cooling rank, for unscheduled outages to your system?"

- The MDCS fails to provide the details and statistics required to relate failures to specific Ground C^3I systems and covers only a portion of the total inventory. The generators and ECUs in several Communications and Electronics (CE) systems are managed by the item managers for those CE systems, and not by the electromechanical equipment item managers. Hence, they do not show up in the 66-1 electromechanical equipment data. Also, much of the power and environmental control equipment is designated: Real Property Installed Equipment (RPIE), which is managed separately, resulting in its absence in the 66-1 data.
- The Equipment Status Report (ESR) data obtainable from the various command headquarters differs greatly from the ESR data generated at the sites. Futhermore, most of the comments do not appear on the printed reports from the computer. Instead, the words: HISTORICAL RECORD appear.

- Condition monitoring can not only predict, detect, and isolate failures, it can verify installation integrity and confirm successful repairs. Combined with Reliability Centered Maintenance, (cf Appendix H) it can help conserve maintenance resources and reduce maintenance-induced failures. PAVE PAWS (Beale) would probably have detected the suspected misalignment responsible for premature failures of two diesel generator pedestal bearings had condition monitoring been employed.

- Condition monitoring is not a panacea, it is a tool. Unmittigated design and maintenance resource deficiencies can defeat the best of tools. Several such deficiencies have been identified in this report.

- The success of condition monitoring depends on having all the other logistics support elements in place including spare parts, repair skills, technical data, etc. In other words, detection, diagnosis and prognosis tools must be complemented by the means to fix and prevent problems.

- The survey and analysis could not be successfully conducted along the lines originally planned because the required information is not available at the depots. Fortunately, The pilot study made it possible to modify the plan before too much of the funds were spent.

- This study identifies problems that could form the basis of several separate studies.

- The lessons-learned reported herein should benefit subsequent PAVE PAWS and similar installations.
- Current Air Force Ground C^3I Systems and others designated in the following table could profit from the results of this study. Most of these would make equally viable candidates for establishing condition monitoring techniques.

OTHER AF GROUND C^3I SYSTEMS APPLICATIONS

The following are potential users of the results of this study.

•	AFSCF (Air Force Satellite Control Facility)
•	AEGIS (Airborne Early Warning/Ground Environment Integration System)
2059	PAVE PAWS (Phased Array Early Warning System) AN/FPS-115
2433	SEEK IGLOO (Long Range Minimally Attended Radar) AN/FPS-117
465L	SAC COC (COMBAT OPERATIONS CENTERS
466L	ELINT System
•	ALSS (Advanced Location Strike System)
633A	COBRA DANE (Phased Array Radar Early Warning System)
•	BETA (Battlefield Exploitation and Target Acquisition Fusion Center)
2295	GEODSS (Ground-based Electro-Optical Deep Space Surveillance System)
•	EPARCS (Enhanced Perimeter Acquisition Radar Characterization System - Grand Forks, N.D.)
414L	OTH-B (Over the Horizon Backscatter)
483L	SECURE G/A/G COMM System)
633B	COBRA JUDY (Shipboard Phased Array Radar)
474N	Sea Launched Ballistic Missile Detector System
496L	SPADATS
•	SPADOC-4 (Space Defense Operations Center Phase 4)
481B	E-4 NEACP (National Emergency Airborne Command Post - Ground Installations)
•	MILSTAR GROUND STATIONS (Military Communications Satellites)
412L	QUICKDRAW (Air Weapons Control System, AN/TSQ 91,2,&3)
•	SEEK FROST, NORTH WARNING (formerly enhanced Dew Line)
492L	JACKPOT (U S Stricom Joint Airborne Communications Cen Command Post) AN/URC-56
968H	ROCCs and GATRs JSS (Joint Surveillance System) AN/FYQ-93 Regional Operations Control Centers and Ground - Air Transmitter/Receivers)
820L	NMCC (National Military Command Centers)
•	ENSCE (Enemy Situation Correlation Element)
428A	TIPI (Tactical Information Processing and Interpretation System)
•	PLSS (Position Location Strike System)
•	SEEK SAIL
•	UPD RADAR
•	TEAL AMBER (Electro-Optical Deep Space Surveillance System - GEODSS Follow-on)
2394	OASIS (Operational Application of Special Intelligence Systems)
425L/427M	NORAD COC (North American Defense Command COC) (ADCOM Cheyenne Mt. Complex)
2294/2467/2486	PACBAR (Pacific Barrier Radar)
	SSS (Strategic Satellite System Ground Stations)

•	JTIDS (Joint Tactical Information Distribution System) AN/URQ-33(V)1
411L	AWACS E-3A Airborne Warning and Control Systems)
•	COMBAT SENT (Signal Collection and Analysis)
•	DRAWSTRING (Automatic Worldwide Surveillance Collection - USAF/N)
•	COBRA SHOE (electronic Fence)
•	FACP (Improved Foreward Air Control Post)
•	CRC/CRP (Control and Reporting Center/Post)
•	GACC (Ground Attack Control Center)
•	TAFLIR

OTHER POTENTIAL USERS (GROUND AND AIRBORNE)

BISS	Base Installation Security Systems
COVERT STRIKE	Bistatic Elint RCVR
NAS	National Airspace System replacement (FAA)
NIS	Nato Identification System
451D	Combat Grande (Spanish C3)
WWMCS	DOD Worldwide Military Communications System
AIRES	Automatic Intelligence Requirements Exploitation System
GWEN	Ground Wave Emergency Network
MEECN	Minimum Essential Emergency Comm Network
TACOMO	Submarine Com Link
2283	JTIDS (Joint Tactical Information Distribution System
•	MALAYSIA CCIS (Command/Control Information System)
GEADGE	German Defense Ground Environment System
DSSCS	Defense Special Security Communication System

NAVY

NAVSPASUR	Navy Space Surveillance System - U.S. Electronic fense
SPS-52C	3D Air Defense Radar
ITSS	Integrated Tactical Surveillance System
ATR CM	Advanced Tactical Radar Countermeasures
TAS/SLQ-32	Ships EW Suite/Target Acquisition System
WAAS	Wide Area Active Surveillance System
MIR	Multitarget Instrumented Radar
BGPHES	Battle Group Phase Horizon Extension System
TEES	Transportable Electronic Exploitation System

ARMY

AGTELIS	Automatic Ground Transportable Emitter Location and Identification System (non-comm signal bearings for targeting)
CIPV	Combat Information Processing Van
TEDS	Tactical Expendable Decoy System (ground launched decoy
CATIS	Computer Aided Tactical Information System
Firefinder	AN/TPQ-36/37 radars
SEMA-X	Special Electronic Mission Aircraft

9.0 PRINCIPAL STUDY RECOMMENDATIONS

Specific recommendations for employing the condition monitoring concepts developed in this report are:

- Allocate funds for a follow-on effort to breadboard, test, and evaluate the condition monitoring techniques established in this study. Conduct the breadboard evaluation on a diesel generator, motor generator, and environmental control unit at a PAVE PAWS-like site.
- Consider the merits of introducing to the depot a diesel engine analyser based on the experience of Long Beach Naval Shipyard.
- Consider providing CEMIRT with a portable diesel engine condition analyser which could distinguish between diesels that can be repaired in-place and those requiring removal for overhaul.
- Expand the current effort to include survey of additional key AF Ground C^3I Systems including JSS, NORAD-HQ, SEEK IGLOO, GEODSS, et.al.
- Fund a similar effort directed toward <u>tactical</u> ground C^3I systems that acknowledges the differences from strategic counterparts including: function, equipment design, operating environment, and operation and maintenance skills.

- Extend the condition monitoring investigation to tactical and strategic <u>airborne</u> C^3I systems.

- Extend condition monitoring and Reliability Centered Maintenance to ground support equipment, including ground power carts and ground airconditioner units.

- Recommend swift transition to the emerging Air Force Product Performance Feedback System, if it can be shown to overcome the MDCS and ESR problems.

- Match diesel engine ratings to projected loads and avoid oversizing to reduce carbon build-up and oil dilution that contribute to failures and reduces useful life of the engines.

- Provide more trained air conditioning mechanics throughout the C^3I support community.

- Ensure that PPFS and VAMOSC overcome the problems identified for the MDCS.

Numerous other important conclusions and recommendations provided throughout the report do not appear here for the purpose of brevity.

APPENDIX

A Bibliography

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E Diesel Generators Managed by S-ALC/MMIRM

F ECUs Managed by SA-ALC/MMIRG

G 'Why and What is Reliability-Centered Maintenance?' by Charles Smith OASD(I&L)BD (April 23, 1976)

H Glossary of Abbreviations/Acronyms/Terms

APPENDIX A
BIBLIOGRAPHY - RESULTS OF
LITERATURE SEARCH/UPDATE

INTRODUCTION

This bibliography represents results of information surveys initiated to support the analysis. It is an update of bibliographies compiled in the course of conducting previous related studies sponsored by RADC and the U.S. Navy.

Other sources include: a specialized listing of textual materials used in Hughes' internal applications, Hughes Technical Library Information Retrieval Service, and produced listings originating in NASA and two internal archives.

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b. VM-1/2-78, Vibration Analysis

AMERICAN SOCIETY OF HEATING REFRIGERATING, AND AIR CONDITIONING ENGINEERS, INC. (ASHRAE)

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APPENDIX B

PAVE PAWS SELECTED EQUIPMENT STATUS REPORTS

- BEALE AFB
- OFFUTT AFB

02-20-82 THIS LIST IS UNCLASSIFIED

PREPARED 20 FEB 82 SELECTED FSR DATA FOR BEALE

TMS OR FIS ICN	SERIAL NUMBER	NUC	CMN	JSR NUMBER	D T	C C	START YR	MO	DA	TIME	STOP YR	MO	DA	TIME	DOWN HRS	COMMENTS
OK339	A07007			3560066	N	R	80	12	21	0838	80	12	21	0843	.1	HISTORY RECORD 8101191200
OK339	B07007			1948812	N	R	81	07	03	2336	81	07	03	2355	.3	HISTORY RECORD
OK339	B07007		100	3440042	N	R	81	12	10	2351	81	12	11	0012	.4	345 SITE GREEN. B2CB, RCL 1 AND CONSOLES 3 345 AND 4 DOWN DUE TO UPS 1 FAILURE. UPS 1 345 DID NOT GO TO STATIC BY-PASS. REPLACED 345 2 INVERTER LEG FUSES.
OK339	B07007		100	3520067	N	R	81	12	18	0030	81	12	18	0137	1.1	352 SITE GREEN. B1CB, RCL A AND CONSOLES 5 352 AND 6 DOWN DUE TO UPS 1 FAILURE. UPS 1 352 DID NOT GO TO STATIC BYPASS. REPLACED 4 352 INVERTER LEG FUSES. REBOOTED RCL AND 352 RELOADED CONSOLES.
OK339	B07007		100	0090025	N	R	82	01	09	1655	82	01	09	1943	2.8	009 SITE GREEN, P1CA, RCL 1 DOWN. UPS1 IN STATIC 009 BYPASS. UPS1 BYPASSED TO COMMERCIAL.
FFS115	000002		050	2640040	N	R	81	09	21	0801	81	09	21	0807	.1	HISTORY RECORD
~~FPS115~~	~~000002~~		~~051~~	~~0090028~~	~~N~~	~~A~~	~~82~~	~~01~~	~~09~~	~~1900~~	82	01	09	2001	1.0	009 SITE GREEN. B2CB, FIS1 & UPS1 DOWN. 009 UPS1 BYPASSED TO COMMERCIAL.
~~FYK013~~	~~A00625~~			~~3560067~~	~~N~~	~~A~~	~~80~~	~~12~~	~~21~~	~~0847~~	~~80~~	~~12~~	~~21~~	~~1140~~	2.9	HISTORY RECORD 8101191200
FYK013	A00625			3560068	N	A	80	12	21	0847	80	12	21	1005	1.3	HISTORY RECORD 8101191200
FYK013	B00625			1870019	N	R	81	07	06	2053	81	07	06	2235	1.7	HISTORY RECORD
FYK013	B00625		300	0090026	N	R	82	01	09	1655	82	01	09	2003	3.2	009 SITE GREEN, P2CB, CYB B DOWN, UPS1 IN STATIC 009 BYPASS. UPS1 BYPASSED TO COMMERCIAL.
FYK013	B00625		763	0090031	N	A	82	01	09	1655	82	01	10	1345	20.8	009 SITE GREEN, P1CA, SYS17-3 DOWN DUE TO 009 UNSTABLE INPUT POWER. SYS RESTORED WHEN 009 ATTACHED TO ALTERNATE MOTOR GENERATOR.

Local Time Local Time

MoDoomp (Rcl)

RADAR

Cyber 174/12

Power Outage

USERID DCLMC1 THIS PRODUCT CONTAINS UNCLASSIFIED DATA

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TMS OS MISSION	SERIAL NUMBER	WUC	CHN	ESR NUMBER	O T	P	C C	----START---- YR MO DA TIME	----STOP---- YR MO DA TIME	DOWN HRS	COMMENTS
ZCATALIN	2156ZZ			356Z065	N		R	80 12 21 0740	80 12 21 0830	.8	HISTORY RECORD
ZDATALIN	2156ZZ			079Z051	N		R	81 03 20 1325	81 03 20 1332	.1	HISTORY RECORD
ZCATALIN	2156ZZ			079Z052	N		R	81 03 20 1340	81 03 20 1453	1.2	HISTORY RECORD
ZCATALIN	2156ZZ			079Z052A	N		R	81 03 20 1453	81 03 20 1510	.3	HISTORY RECORD
ZCATALIN	2156ZZ			079Z053	N		R	81 03 20 1637	81 03 20 1728	.9	HISTORY RECORD
ZCATALIN	2156ZZ			079Z053A	N		R	81 03 20 1749	81 03 20 1844	.9	HISTORY RECORD
ZCATALIN	2156ZZ			089Z073	N		R	81 03 30 0815	81 03 30 0819	.1	HISTORY RECORD
ZCATALIN	2156ZZ			089Z075	N		R	81 03 30 0826	81 03 30 0851	.4	HISTORY RECORD
ZCATALIN	2156ZZ			089Z075A	N		R	81 03 30 0851	81 03 30 0853	.1	HISTORY RECORD
ZCATALIN	2156ZZ			100Z034	N		R	81 04 10 0517	81 04 10 0621	1.1	HISTORY RECORD
ZDATALIN	2156ZZ			100Z034A	N		R	81 04 10 0648	81 04 10 0655	.1	HISTORY RECORD
ZCATALIN	2156ZZ			173Z041	N		R	81 06 22 1528	81 06 22 1535	.1	HISTORY RECORD
ZCATALIN	2156ZZ			173Z041A	N		R	81 06 22 1535	81 06 22 1541	.1	HISTORY RECORD
ZDATALIN	2156ZZ			173Z041B	N		R	81 06 22 1541	81 06 22 1546	.1	HISTORY RECORD
ZDATALIN	2156ZZ			173Z041C	N		R	81 06 22 1546	81 06 22 1549	.1	HISTORY RECORD
ZCATALIN	2156ZZ			167Z016	N		R	81 07 06 1905	81 07 06 2042	1.6	HISTORY RECORD

DATA LINES TO NORAD/SAC/NMCC/ANMCC

USERID PCLM01

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IMS 03 MISSION	SERIAL NUMBER	WUC	CHN	ESR NUMBER	D T	D L	C	START YR MO DA TIME	STOP YR MO DA TIME	DOWN HRS	COMMENTS
ZCATALIN	215622			1952039	N		R	81 07 14 0409	81 07 14 0431	.4 .4	HISTORY RECORD HISTORY RECORD
ZDATALIN	215622			1952039A	N		R	81 07 14 0431	81 07 14 0438	.1 .1	HISTORY RECORD HISTORY RECORD
ZCATALIN	215622			3457043	N		R	81 12 11 0012	81 12 11 0022	.2	345 SITE REP. R2CB. BOTH IPS DOWN. UPS 1 345 DOWN PREVIOUSLY. REF ESR 3440042. PRE- 345 LIMINARY INVESTIGATION REVEALS THAT WHEN 345 UPS 1 WAS RESTORED ON-LINE, A MOMENTARY 345 POWER SURGE WAS INCURRED THROUGH UPS 2 345 CAUSING RCL 2 TO DROP TO IDLE. BOTH RCLS 345 REBOOTED AFTER VERIFYING THAT UPS 1 AND 345 UPS 2 WERE OPERATIONAL. SYSTEM RESTORED 345 AFTER INITIALIZATION ON RCL 1 AND CYE 0.
ZDATALIN	215622			3522068	N		R	81 12 16 0108	81 12 18 0118	.2	352 SITE REP. R2CB. UPS 2 DOWN, CAUSING LOSS 352 OF POWER TO BOTH RCLS. UNKNOWN AS TO WHY 352 UPS 2 DROPPED. UPS 2 RESTORED BY RESET- 352 TING SYSTEM ALARM. BOTH RCLS REBOOTED. 352 UPS 1 DOWN. REF ESR 3520067.
ZCATALIN	215622			0092024	N		R	82 01 09 1655	82 01 09 1716	.4	009 SITE REP. R1CA. BOTH RCLS DOWN. RCL 2 009 REBOOTED.
ZCATALIN	215622			0092024A	N		R	82 01 09 1816	82 01 09 1921	.1	009 SITE REP R2CB RCL2 DOWN RCL1 DOWN ALREADY 009 REF ESR 0090025. REBOOTED RCL2.
ZMSLWARN	215600			0790051	N		R	81 03 20 1325	81 03 20 1332	.1	HISTORY RECORD
ZMSLWARN	215600			0790052	N		R	81 03 20 1340	81 03 20 1453	1.2	HISTORY RECORD
ZMSLWARN	215600			0790052A	N		A	81 03 20 1453	81 03 20 1510	.3	HISTORY RECORD
~~ZMSLWARN~~	~~215600~~			~~0790053~~	~~N~~		~~R~~	~~81 03 20 1637~~	~~81 03 20 1728~~	~~.9~~	~~HISTORY RECORD~~
ZMSLWARN	215600			0790053A	N		A	81 03 20 1749	81 03 20 1844	.9	HISTORY RECORD

Early Warning Mission

USERID OCLM01 THIS PRODUCT CONTAINS UNCLASSIFIED DATA

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PREPARED 20 FEB 82 SELECTED ESR DATA FOR REALE

IMS 03 MISSION	SERIAL NUMBER	WUC	CHN	ESR NUMBER	D T	C S	C C	START YR	MO	DA	TIME	STOP YR	MO	DA	TIME	DOWN HRS	COMMENTS
ZMSLWARN	215600			0890073	N		F	81	03	30	0815	81	03	30	0818	.1	HISTORY RECORD
ZMSLWARN	215600			0890075	N		R	81	03	30	0826	81	03	30	0851	.4	HISTORY RECORD
ZMSLWARN	215600			0890075A	N		A	81	03	30	0851	81	03	30	0858	.1	HISTORY RECORD
ZMSLWARN	215600			1000034	N		R	81	04	10	0517	81	04	10	0621	1.1	HISTORY RECORD
ZMSLWARN	215600			1000034A	N		A	81	04	10	0621	81	04	10	0643	.5	HISTORY RECORD
ZMSLWARN	215600			1000034B	N		R	81	04	10	0648	81	04	10	0655	.1	HISTORY RECORD
ZMSLWARN	215600			1000034C	N		R	81	04	10	0655	81	04	10	0800	1.1	HISTORY RECORD
ZMSLWARN	215600			1030529A	N		A	81	04	13	1400	81	04	13	1526	1.4	HISTORY RECORD
ZMSLWARN	215600			1030529C	N		A	81	04	13	1532	81	04	13	1544	.2	HISTORY RECORD
ZMSLWARN	215600			1730041	N		R	81	06	22	1528	81	06	22	1535	.1	HISTORY RECORD
ZMSLWARN	215600			1730041A	N		A	81	06	22	1535	81	06	22	1541	.1	HISTORY RECORD
ZMSLWARN	215600			1730041B	N		R	81	06	22	1541	81	06	22	1546	.1	HISTORY RECORD
ZMSLWARN	215600			1730041C	N		A	81	06	22	1546	81	06	22	1549	.1	HISTORY RECORD
ZMSLWARN	215600			1870016	N		R	81	07	06	1905	81	07	06	2342	1.6	HISTORY RECORD
ZMSLWARN	215600			1950038	N		R	81	07	14	0409	81	07	14	0431	.4	HISTORY RECORD
ZMSLWARN	215600			1950038A	N		A	81	07	14	0431	81	07	14	0433	.1	HISTORY RECORD

USERID CCLM01 THIS PRODUCT CONTAINS UNCLASSIFIED DATA

02-20-82

THIS LIST IS UNCLASSIFIED

PREPARED 26 FEB 82

SELECTED ESR DATA FOR BEALE

TMS OR MISSION	SERIAL NUMBER	HUC	CMN	ESR NUMBER	D T	D C	C C	---START--- YR MO DA TIME	---STOP--- YR MO DA TIME	DOWN HRS	COMMENTS
ZMSLWARN	215600			2640039	N		R	81 09 21 0727	81 09 21 0737	.2	HISTORY RECORD
ZMSLWARN	215600			2640039A	N		R	81 09 21 0739	81 09 21 0758	.3	HISTORY RECORD
ZMSLWARN	215600		050	2640040	N		R	81 09 21 0801	81 09 21 0807	.1	HISTORY RECORD
~~ZMSLWARN~~	~~215600~~			~~3450043~~	~~N~~		~~R~~	~~81 12 11 0012~~	~~81 12 11 0022~~	.2	345 SITE REP. R2C8. BOTH UPS DOWN. UPS 1 345 DOWN PREVIOUSLY, REF ESR 3440042. PRE- 345 LIMINARY INVESTIGATION REVEALS THAT WHEN 345 UPS 1 WAS RESTORED ON-LINE, A MOMENTARY 345 POWER SURGE WAS INCURRED THROUGH UPS 2 345 CAUSING RCL 2 TO DROP TO IDLE. BOTH RCLS 345 REBOOTED AFTER VERIFYING THAT UPS 1 AND 345 UPS 2 WERE OPERATIONAL. SYSTEM RESTORED 345 AFTER INITIALIZATION ON RCL-1 AND CYB 6.
ZMSLWARN	215600			3520068	N		R	81 12 10 0108	81 12 10 0119	.2	352 SITE REP. R2C8. UPS 2 DOWN, CAUSING LOSS 352 OF POWER TO BOTH RCLS. UNKNOWN AS TO WHY 352 UPS 2 DROPPED. UPS 2 RESTORED BY RESET- 352 TING SYSTEM ALARM. BOTH RCLS REBOOTED. 352 UPS 1 DOWN, REF ESR 3520067.
ZMSLWARN	215600			0090024	N		R	82 01 09 1655	82 01 09 1716	.4	009 SITE REP. R1CA. BOTH RCLS DOWN. RCL 2 009 REBOOTED.
ZMSLWARN	215600			0090024A	N		R	82 01 09 1816	82 01 09 1821	.1	009 SITE REP. R2C8. RCL2 DOWN. RCL1 DOWN ALREADY 009 REF ESR 0090025. REBOOTED RCL2.
ZMSLWARN	215622			3560065	N		R	80 12 21 0740	80 12 21 0930	.8	HISTORY RECORD 8101191200

END OF DATA FOR BEALE

USERID CCLV01

THIS PRODUCT CONTAINS UNCLASSIFIED DATA

02-20-82 THIS LIST IS UNCLASSIFIED

~~PREPARED 20 FEB 82~~ ~~SELECTED ESP DATA FOR~~ BUZZARDS BAY

TMS OR MISSION	SERIAL NUMBER	WUC	CMN	ESS NUMBER	C Y	R C	C C	START YR	MO	DA	TIME	STOP YR	MO	DA	TIME	DOWN HRS	COMMENTS
OK339	000001	AF000		3390010	N		R	80	12	04	1641	80	12	04	1649	.1	HISTORY RECORD
~~OK339~~	~~000001~~	~~AF000~~		~~3400004~~	~~N~~		~~R~~	~~80~~	~~12~~	~~05~~	~~1314~~	~~80~~	~~12~~	~~05~~	~~1322~~	~~.1~~	~~HISTORY RECORD~~
OK339	000001	AF000		3410003	N		R	80	12	06	0213	80	12	06	0220	.1	HISTORY RECORD
OK339	000001	AF000		3430004	N		R	80	12	08	1030	80	12	08	1046	.8	HISTORY RECORD
OK339	000002	AF000		3440005	N		R	80	12	09	0925	80	12	09	0932	.1	HISTORY RECORD
FPS115	000001	~~A1000~~		~~3470005~~	~~N~~		~~R~~	~~80~~	~~12~~	~~12~~	~~0900~~	80	12	12	0915	.2	HISTORY RECORD
FPS115	000001	XXXXX		0371003	N		R	81	02	06	1054	81	02	06	1117	.4	HISTORY RECORD
FPS115	000001	XXXXX		2171005	N		R	81	08	05	1710	81	08	05	1725	.3	HISTORY RECORD
FPS115	000001	XXXXY		3391005	N		R	81	12	05	1941	81	12	05	1947	.1	SITE REP. LOST BOTH UPS 1 AND 2 WHEN SITE PCWR PLNT SWITCHED FROM COMM PWR TO DIESEL PWR. RESET BOTH UPS SYS ON LINE RICA.
FPS115	000001	XXXXX		33910053	N		R	81	12	05	1957	81	12	05	2015	.3	SITE REP. RICA. RCL 1 HALTED AFTER PWR SURGE FROM UPS 1. REBOOTED RCL 1 WITH FULL INITIALIZATION TWO TIMES BEFORE RCL 1 ATTACHED TO CYBER A.
FPS115	000001	XXXXX	XXX	0141009	N		R	82	01	14	1307	82	01	14	1350	.7	R2C8. BOTH UNINTERRUPTABLE POWER SUPPLIES, UPS, TRIPPED, REMOVING PRIMARY POWER TO RCL.S AND OTHER ASSOCIATED RADAR AND COMPUTER EQUIPMENT. WHEN ATTEMPTING TO RESTORE POWER TO THIS EQUIP BY SWITCHING THE UPS TO BYPASS, BOTH MOTOR GENERATORS FAILED, REMOVING POWER TO THE REST OF THE EQUIP. BOTH MOTOR GENERATORS WERE RESTARTED, BOTH UPS RETURNED TO AUTOMATIC, RADAR & COMPUTER EQUIP RESTORED.
FYK613	8X0816	2ME20		3143002	N		4	80	11	05	1835	80	11	09	2332	5.1	HISTORY RECORD
FYK613	8X0-16	2ME00		3143002	N	2	3	80	11	05	1836	80	11	09	2335	4.1	HISTORY RECORD

USERID OFLMC1 THIS PRODUCT CONTAINS UNCLASSIFIED DATA

PREPARED 26 FEB 82 SELECTED ESR DATA FOR BUZZARDS BAY

TMS 03 MISSION	SERIAL NUMBER	WUC	JPN	ESR NUMBER	D T	U C	C C	START YR	START MO	START DA	START TIME	STOP YR	STOP MO	STOP DA	STOP TIME	DOWN HRS	COMMENTS
FYK013	000816	C4000		3430004	N		R	80	12	08	1009	80	12	08	1043	.7	HISTORY RECORD
FYK013	000816	CWF00	761	0141002	N		A	82	01	14	0330	82	01	14	0402	.5	R2CA. SYSTEM 17-1 DOWN. INPUT POWER CIRCUIT BREAKER TRIPPED. MAINT RESET BREAKER AND RE-LOADED SYSTEM.
FYK013	000819	CWE00	761	2731010	N		A	81	09	30	2300	81	09	30	2314	.2	HISTORY RECORD
FYK013	000819	CWE00	761	2741001	N		A	81	10	01	0110	81	10	01	0534	4.3	HISTORY RECORD
FYK013	000819	CWA00	761	0321007	N		A	82	02	01	1016	82	02	01	1034	.3	R2CB. SYSTEM 17-1 DOWN DUE TO TRIPPED CKT BREAKER. CKT BREAKER RESET AND BOOTSTRAP RELOADED. SYSTEM 17-1 UP.
ZDATALIN	216500	XXXXX		3090066	N		R	80	11	04	1310	80	11	04	1318	.1	HISTORY RECORD
ZDATALIN	216500	XXXXX		3090006A	N		R	80	11	04	1500	80	11	04	1504	.1	HISTORY RECORD
ZDATALIN	216500	XXXXX		3090006B	N		R	80	11	04	1532	80	11	04	1612	.7	HISTORY RECORD
ZDATALIN	216500	AF000		3390010	N		R	80	12	04	1641	80	12	04	1651	.2	HISTORY RECORD
ZDATALIN	216500	AF000		3440005	N		R	80	12	09	0925	80	12	09	0932	.1	HISTORY RECORD
ZDATALIN	216500	AA000		3470005	N		R	80	12	12	0909	80	12	12	0921	.2	HISTORY RECORD
ZDATALIN	216500	XXXXX		2171005	N		R	81	08	05	1710	81	08	05	1725	.3	HISTORY RECORD
ZDATALIN	216500	XXXXX		2502008	N		R	81	09	07	2215	81	09	08	0023	2.1	HISTORY RECORD
ZDATALIN	216500	XXXXX		3391005	N		R	81	12	05	1941	81	12	05	1947	.1	
ZDATALIN	216500	XXXXX		33910059	N		R	81	12	05	1957	81	12	05	2015	.3	

USERID CFLM01

THIS PRODUCT CONTAINS UNCLASSIFIED DATA

82-20-82 THIS LIST IS UNCLASSIFIED

~~PREPARED 20 FEB 82~~ ~~SELECTED ESR DATA FOR~~ BUZZARDS BAY

TMS OR MISSION	SERIAL NUMBER	WUC	CHN	ESR NUMBER	D T	D C	C C	START YR	START MO	START DA	START TIME	STOP YR	STOP MO	STOP DA	STOP TIME	DOWN HRS	COMMENTS
ZCATALIN	216500	XXXXX	XXX	0141009	N		R	82	01	14	1307	82	01	14	1350	.7	
~~ZMSLWARN~~	~~216500~~	~~XXXXX~~		~~3090006~~	N		~~R~~	~~80~~	~~11~~	04	1310	80	11	04	1318	.1	~~HISTORY RECORD~~
ZMSLWARN	216500	XXXXX		3090006A	N		R	80	11	04	1500	80	11	04	1504	.1	HISTORY RECORD
ZMSLWARN	216500	XXXXX		3090006B	N		R	80	11	04	1532	80	11	04	1612	.7	HISTORY RECORD
ZMSLWARN	216500	AF000		3390010	N		R	80	12	04	1641	80	12	04	1648	.1	HISTORY RECORD
~~ZMSLWARN~~	~~216500~~	~~AF000~~		~~3390010A~~	N		A	~~80~~	12	~~04~~	1649	80	12	04	1651		HISTORY ~~RECORD~~
ZMSLWARN	216500	CA000		3430004	N		R	80	12	08	1010	80	12	08	1024	.2	HISTORY RECORD
ZMSLWARN	216500	CA000		3430004A	N		A	80	12	08	1025	80	12	08	1054	.5	HISTORY RECORD
ZMSLWARN	216500	AF000		3440005	N		R	80	12	09	0925	80	12	09	0932	.1	HISTORY RECORD
~~ZMSLWARN~~	~~216500~~	~~AA000~~		~~3470005~~	N		R	~~80~~	12	12	0909	80	12	12	0918	.2	HISTORY RECORD
ZMSLWARN	216500	XXXXX		0371003	N		R	81	02	06	1054	81	02	06	1117	.4	HISTORY RECORD
ZMSLWARN	216500	XXXXX		1711005A	N		A	81	06	20	1941	81	06	20	1954	.2	HISTORY RECORD
ZMSLWARN	216500	XXXXX		2171005	N		R	81	08	05	1710	81	08	05	1725	.3	HISTORY RECORD
ZMSLWARN	216500	XXXXX		2501008	N		A	81	09	07	2215	81	09	07	2222	.1	HISTORY RECORD
ZMSLWARN	216500	XXXXX		2501008A	N		F	81	09	07	2222	81	09	07	2228	.1	HISTORY RECORD
ZMSLWARN	216500	XXXXX		2501008B	N		A	81	09	07	2228	81	09	08	0023	1.9	HISTORY RECORD
ZMSLWARN	216500	XXXXX		2511001	N		R	81	09	08	0851	81	09	08	0900	.2	HISTORY RECORD

USERID DCLM01

THIS PRODUCT CONTAINS UNCLASSIFIED DATA

02-20-82

THIS LIST IS UNCLASSIFIED

~~PREPARED 20 FEB 82~~

SELECTED ESR DATA FOR BUZZARDS BAY

TMS 03 MISSION	SERIAL NUMBER	MUC	CMN	ESR NUMBER	D	C	C	----START---- YR MO DA TIME	----STOP---- YR MO DA TIME	DOWN HRS	COMMENTS
ZMSLWARN	216500	XXXXX		3391003	N		R	81 12 05 1332	81 12 05 1349	.3	SYSTEM DOWN TO TRANSFER UPS-1 ON-LINE, RCL-2 DOWN TO PAINT REF ESR 3371004. UPS-1 ON-LINE AND SYSTEM IS STABLE.
~~ZMSLWARN~~	~~216500~~	~~XXXXX~~		~~3391005~~	~~N~~		~~R~~	~~81 12 05 1941~~	~~81 12 05 1947~~	.1	
ZMSLWARN	216500	XXXXX		33910058	N		R	81 12 05 1957	81 12 05 2015	.3	
ZMSLWARN	216500	XXXXX	XXX	C141009	N		R	82 01 14 1307	82 01 14 1353	.7	
ZSPACETR	216500	XXXXX		3090006	N		R	80 11 04 1310	80 11 04 1318	.1	HISTORY RECORD
~~ZSPACETR~~	~~216500~~	~~XXXXX~~		~~3090006A~~	~~N~~		~~R~~	~~80 11 04 1500~~	~~80 11 04 1504~~	.1	~~HISTORY RECORD~~
ZSPACETR	216500	XXXXX		3090006A	N		R	80 11 04 1532	80 11 04 1612	.7	HISTORY RECORD
ZSPACETR	216500	AF000		3390010	N		R	80 12 04 1641	80 12 04 1645	.1	HISTORY RECORD
ZSPACETR	216500	XXXXX		3430004	N		R	80 12 08 1010	80 12 08 1024	.2	HISTORY RECORD
~~ZSPACETR~~	~~216500~~	~~AF000~~		3440005	N		R	80 12 09 0925	80 12 09 0932	.1	HISTORY RECORD
ZSPACETR	216500	AA000		3470005	N		R	80 12 12 0909	80 12 12 0918	.2	HISTORY RECORD

SPACETRACK

~~END OF DATA FOR BUZZARDS BAY~~

END

USERID OFLM01

THIS PRODUCT CONTAINS UNCLASSIFIED DATA

APPENDIX C

'AVAILABLE FAILURE AND MAINTENANCE DATA ON POWER AND AIR CONDITIONING UNITS', LETTER FROM ESC/LGM DATED 4 MAY 1982 (PLUS ATTACHMENTS)

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS ELECTRONIC SECURITY COMMAND
SAN ANTONIO, TEXAS 78243

4 MAY 1982

REPLY TO ATTN OF: LGM

SUBJECT: Available Failure and Maintenance Data on Power and Air Conditioning Units

TO: Hughes Aircraft Company
ATTN: Mr Robert R. Holden
P.O. Box 90515
Los Angeles, CA 90009

1. Since we received your letter of 24 September 1981, we have been trying to find sources of the information that you requested without very much success. We can write in general terms what our problems are, but generally no specific data is collected on outages due to failures of power and air conditioning. Thus, the following paragraphs describe in general terms the type of facilities we have and the problems that we have run into.

2. Our fixed plant facilities are carefully designed to give the maximum reliability on power and air conditioning. In nearly all units of this type, we have commercial power, 50 Hz overseas and 60 Hz in the United States, and this is backed up by what we call 200% back-up power. Our definition is that we have enough diesel engine generators to provide 100% of our connected power load and have at least one additional power unit of the largest type so that we can have one down for repair and still pick up full power load upon the failure of commercial power. We further divide the power into two power subsystems or busses which can be cross-connected in an emergency. One is technical power, and the other is utility power which provides power to lighting, air conditioning, and other not so critical power users. One benefit of this division is that cycling of air conditioning loads is not readily reflected in voltage variations on technical power fed to computers, receivers, recorders, etc. We very seldom have a failure on the power distribution system that is not expected, but these can cause bad problems (attachment 1). We do occasionally have to schedule power downtimes of sometimes up to six or eight hours to rework a substation or some of the power distribution equipment inside of the station (attachment 2). Interruption of commercial power, even though we do have provisions for rapid start of diesel generators, can cause some mission difficulties which will be discussed later. Some of our overseas units have commercial power that is subject to supposedly scheduled power outages. Some of these power outages are due to a rotating overload which is shared by different users. For example, they may not have any power for a certain three hours on every Tuesday and in other instances it is the company's necessity to shut down some of their generating equipment in order to service it because they have no spare units. A recent report told of the loss of eight hours of computer work because one of the scheduled power outages was due to occur at 8:30 a.m. and the power company pulled the plug at 7:30 a.m. Everything in the computer memories was lost because they

hadn't had a chance to unload the memories onto magnetic tape (attachment 3).

3. Our fixed station air conditioning systems are likewise generally large and multi-unit so that we can lose one compressor and still have some air conditioning available. What can cause us a large amount of difficulty is the loss of an air handling unit because then we cannot supply air conditioning to a specific area. In some of our larger stations, we even have more than one zone with multiple air handling units which feed air into a large operational room. The supplying of the right amount of cooling at a critical point is a serious problem and has not been solved in as good a manner as we would like (attachment 4). Currently, we are mounting some critical mission equipment on raised flooring with air conditioning fed into the under-floor area as a plenum and cutting holes through the raised floor into the high heat equipment. Even this sometimes does not work as well as we would like because of the equipment temperatures exceeding the design levels while operators freeze to death in front of the equipment from air leaks between equipment panels. Sometimes the air inside is entering at a temperature of about 45-50 degrees and even a pinhole leak can be very uncomfortable. Another of our air conditioning methods of failure is stopped-up water drains on the cooling coils. We have one station that has a yearly flooding problem from this nearly every spring. Lint from some of the local plants flies in the air, gets into the building, and eventually ends up in the drain pipe for the water. The net result is water leaking down onto the electrical equipment, and sometimes it is necessary to shut down selected equipments for as much as a day or two while all the stoppages are found and cleaned out of the piping.

4. The operational impact of power failures and surges on equipment is a constant problem (attachment 5). We have found that the best remedy for a power surging condition is to turn everything off. The operators have been trained to throw the switches when they see the lights get bright or dim. In one instance, the quick action of one operator saved a ground-to-air circuit which also, incidentally, could talk to a distant ground station, and it was the only comm link operational for a period of about eight hours. All other equipments contained blown transistors which had to be hunted down and replaced. This particular happening was a classic example to us of how vulnerable we are to line voltage variations. We estimate that about 80% of the station's electrical equipment suffered at least some damage and it took nearly six weeks to get everything completely repaired. We were about 90% operational within approximately eight hours.

5. The proper cooling of equipment is also a problem and nearly every day brings a report of a piece or two of equipment that has suffered loss of operation or damage due to variations in cooling. Most of these are the result of spot overheating in the equipment racks. Quite frequently there will be a report of an unusually hot day. The equipment becomes erratic in operation and the people noticing the difficulty turn the equipment off, turn off the lowest priority equipment, and get back operational within about

30 minutes. Sometimes the problem is due to human error such as missing the weekly or daily cleaning of an air intake filter, or a scrap of paper is sucked up into the intake which reduces the air flow, or maintenance work in progress has a door open or a panel removed so that the normal air flow is disrupted. We do have a number of very critical equipments in that experience has shown that they do not actually have the ability to tolerate a variation in temperature range that the design specifications call for. There is a continual effort by maintenance personnel to try to correct some of these problems which may have been caused by changing the equipment placement in racks in order to meet operational requirements or adding just another piece of small equipment for a new mission, etc.

6. On air conditioning of our fixed stations, we have a very short time that they can operate without any air conditioning of any kind. Sometimes the period is as short as 30 minutes. We are attaching a plan that one of the units developed for use when they knew that they were going to have a total air conditioning loss in a portion of one of their buildings (attachment 6).

7. In the past we attempted to use uninterrupted power supplies for some of our critical communications circuit power. These units were a large flywheel on a motor generator system with an electrical clutch. Whenever a prime power source failed, the clutch would close, and the flywheel would start a diesel engine which then would provide the power source. In these these equipments could restore power with a loss of about two cycles of power. In practical use, they caused more power failures than what we were experiencing with the commercial power. The cause of this was the fact that the system had to run continuously and could not be taken off-line for servicing. We found that we always lost crypto sync when we tried to go back to commercial power because the commercial power would not be in phase with the running engine generator and there was enough of a surge when the moving flywheel tried to get in sync with commercial power that several cycles of power would be lost (attachment 7).

8. Our mobile units use a variety of power units. These are the types that are presently in use:

MB-17	60 Hz	60 kw
MB-18	60 Hz	60 kw
MB-19	60 Hz	80 kw
MIP-006A	60 Hz	60 kw
A/E24U-8	400 Hz	60 kw

When we deploy we normally take along one or two extra power units so that we can keep operational in spite of power unit difficulties. We also send a power production technician and a number of spare parts on deployment. In some instances the power units have required considerable work such as replacement of fuel pumps, cleaning of fuel lines filters, and so forth, because of

contaminated fuel. The fueling of the power units is a difficulty in that they have to be shut down and cooled off in order to put fuel in the tanks which are generally located above the engine. If we stay on deployment for a period of time, we will attempt to install piping so that the fuel can be pumped into the tank without danger of fire. Extended deployment usually leads to a need to rework the power generators in the field (attachment 8).

9. Our mobile units use shelters of about four different types. Some of the older ones use a window-style air conditioner which extends through the wall and can be pushed out once the shelter is placed for use. These generally are rather easy to replace but loss of the air conditioner with no replacement on hand is a serious problem because there are no windows or ventilating means. The most modern shelters use one of the following list of environmental units which are external to the shelter and are connected by means of flexible ducting:

ECU-17 CARRIER 26000
ECU-24
ECU-26
ECU-27

Normally one environmental unit services one shelter only. In an emergency, they have run two shelters from one unit with a reduced heat load. Air conditioning is also required because the shelters do not have windows or other means of ventilation, and they contain a large number of electrical equipment which produces a high heat load. We run into some problems sometimes when there is three feet of snow on the outside and we have to run our air conditioning equipment. There have been a few instances where they have tried to use the cold outside air, but this is generally not satisfactory as the air is either too cold or too hot, and moisture is built up inside the shelter.

10. We have extracted information from a few messages to give you an idea of the type of information that we have. Generally, we only get information on equipment failures or mission failures. Most of our people are very ingenious and somehow muddle through in spite of all of the difficulties that we have. Occasionally, we do get a total failure and it is necessary to borrow an engine generator or environmental control unit sometimes even from several hundred miles away.

11. We hope this information is useful to you in your study.

Chester P. Wilkes
CHESTER P. WILKES
Tech Adv, Dir, Maint & Plant Engr
DCS/Logistics

8 Atch
1. 010020Z Apr 82
2. 061345Z Apr 82
3. 060830Z Apr 82
4. 190500Z Apr 82
5. Halt Report Nr 016
6. Message Extract
7. Message Extract 130110Z Apr 82
8. 291305Z Apr 82

R 010020Z APR 82 27 MDC ALT VIC

TO RUQVAAA/HQ ESC KELLY AFB TX//DEM/LGMM/LGS//
INFO RUHVAAA/HQ ESP HICKAM AFB HI//LG//
BT
UNCLAS E F T O
SUBJ: CIRCUIT BREAKER FAILURE, FLR-9 CENTRAL BLDG
REFS: A. MY 090410Z MAR 82
B. ESC/DEM 291544Z MAR 82 (NOTAL)

1. AT 1857Z 29 MAR 82, (0257L, 30 MAR 82) THE COIL IN THE LOW VOLTAGE RELAY IN THE MAIN TIE BREAKER IN OUR FLR-9 CENTRAL BLDG FOR REASONS UNKNOWN, BURNED UP. WE SUBSEQUENTLY LOST OUR DF AND SIGNAL AMPLIFICATION CAPABILITY. BECAUSE OUR UTILITY POWER WAS STILL FUNCTIONING WE HAD LIGHTS AND AIR CONDITIONING IN THE CB. RAPID RESPONSE BY BCE POWER PRODUCTION PERSONNEL ENABLED US TO BE BACK ON THE AIR BY 0300Z (1100L, 30 MAR 82). WE CAME BACK UP BY REPLACING THE TIE BREAKER WITH THE UNUSED CIRCUIT BREAKER ON THE UTILITY SIDE. WE WERE ABLE TO DO THIS BECAUSE, AS DESCRIBED IN REF A, ALL POWER TO THE CB IS BROUGHT DOWN THE TECH SIDE AS A RESULT OF THE UTILITY SIDE TRANSFORMER RE-

PAGE 02
MOVAL IN AUGUST 1980.

2. ONCE WE WERE BACK ON THE AIR, WE LEARNED THAT THE AUTOMATIC RESET MECHANISM IN THE BREAKER WOULD NOT OPERATE, THEREBY REQUIRING US TO RESET MANUALLY IN THE EVENT THE TIE BREAKER TRIPS. WE WERE ALSO CONCERNED AS TO HOW WELL THE MANUAL RESET WOULD WORK. ACCORDINGLY, WE SCHEDULED AN OUTAGE FOR 1100Z (1900L) THAT DAY TO DO MORE TROUBLESHOOTING.

3. WE PULLED THE PLUG AT 1100Z (1910L) AND, USING THE SERVICES OF TWO ELECTRICIANS FROM POWER PRODUCTION, TRIED TO EFFECT REPAIRS ON THE AUTOMATIC RESET AS WELL AS ENSURING IT COULD BE RESET MANUALLY. AFTER AN HOUR'S WORK, WE FOUND THE CIRCUIT BREAKER WOULDN'T PROPERLY RESET MANUALLY AND THAT WE WERE UNABLE TO REPAIR THE AUTOMATIC RESET. ACCORDINGLY, WE REMOVED ITS LOW VOLTAGE RELAY AND INSTALLED IT IN THE ORIGINAL TIE BREAKER. UPON REINSTALLATION OF THE TIE BREAKER, WE FOUND THAT WE COULD MANUALLY RESET IT QUITE HANDILY, BUT THE AUTOMATIC RESET STILL WOULDN'T OPERATE. WE TRIED TO TROUBLESHOOT THE PROBLEM BUT WERE HAMPERED BY A LACK OF SCHEMATICS SHOWING HOW THE ELECTRICAL SYSTEM TIES TOGETHER, AT 1725L (0125Z, 31 MAR 82), SINCE WE WERE GETTING NOWHERE WITH THE TROUBLESHOOTING AND FELT CONFIDENT THE SYSTEM WOULD WORK MANUALLY, WE RESTORED FULL PWER. AT PRESENT

atch 1

M/S

PAGE 03 RHMRAAA1431 UNCLAS E F T O
WE HAVE FULL OPERATIONAL CAPABILITY. HOWEVER, SHOULD THE CIRCUIT BREAKER TRIP, IT WILL BE NECESSARY FOR A TECHNICIAN TO GO OUT TO THE CB TO MANUALLY RESET THE BREAKER AND BRING UP THE EQUIPMENT.
4. THE DAMAGED CIRCUIT BREAKER IS NOW LOCATED IN THE POWER PRODUCTION MAINTENANCE SHOP. THE SUPERINTENDENT, , IS HAVING IT REBUILT FOR US. AS HE HAS NO TECHNICAL DOCUMENTATION ON THIS PARTICULAR CIRCUIT BREAKER, HE HAS SENT A LETTER TO GENERAL ELECTRIC REQUESTING THEY SEND IT TO HIM. I INTEND TO HAVE HIM GO AHEAD AND ORDER SUFFICIENT PARTS TO REBUILD ALL THREE BREAKERS AS I FEEL SURE THEIR ADVANCED AGE MAKES FUTURE PROBLEMS ONLY A MATTER OF TIME.
5. BCE IS WORKING HARD TO GET US BACK WHERE WE BELONG. HOWEVER, ITS SLOW GOING DUE TO OUR LACK OF WIRING DIAGRAMS. IF YOU HAVE ANY DIAGRAMS IN THE HEADQUARTERS WHICH SHOW HOW OUR SWITCHING GEAR IS WIRED UP, WE COULD USE IT HERE. WILL KEEP YOU ADVISED ON THE SITUATION.
BT
#1431

NNNN

R 061345Z APR 82 49/MDC ALT VIC

TO HQ ESC//DEM//
INFO HQ ESC//LG//
AFSSC USAFE//DEMO//

ZEM
UNCLAS E F T O
SUBJ: ESC-DEM(AR)6601 REPORT, REQUEST FOR A SCHEDULED OPERATIONS OUTAGE

1. THE PURPOSE OF THIS POWER OUTAGE IS THE CERTIFICATION AND TEST OF THE NEWLY INSTALLED ENGINE CONTROLS AND MATRIX SWITCHING SYSTEMS (PROJECT NO. CHI 80-0052) IN THE BLDG 600 POWER PLANT.
2. THIS WILL INCLUDE A FULL TEST OF THE AUTOMATIC START AND TAKEOVER OF THE BUILDING'S POWER DISTRIBUTION LOAD WHEN ENCOUNTERING A COMMERCIAL POWER FAILURE. THIS MUST BE ACCOMPLISHED SEVERAL TIMES WITHIN THIS PERIOD OF 8 HOURS, I.E., BRING UP AND DOWN, ETC. DURING THIS TESTING ALL MISSION EQUIPMENT WILL BE POWERED DOWN AND REMAIN DOWN.
3. PRIMARY PROPOSED DATE: 22 MAY 82/ALT PROPOSED DT: 29 MAY 82
4. TIME PROPOSED: 2200Z - 0600Z 82
5. CONTINGENCY PLAN: STOP TESTING AND RETURN TO COMMERCIAL POWER.
#2921

NNNN

	ACTION	INFO
LGM		
LGMF		
LGMP		
LGMO		
LGMG		
LGMA		

ON DE LG

M/RF

atch 2

001
L 61

(R)260530Z APR 82 53/MDC ALT VIC

TO RUQVAAF/HQ ESC KELLY AFB TX//DO RJ/DOSL/LGMS/XPZA//

LGM	X	INFO
D	49	
LGMJ	48	
...C		
L...		
LGMA	✓	

BT
UNCLAS E F T O
SUBJ: MARCH GPS STATUS REPORT

1. MARCH WAS A VERY GOOD MONTH FOR THE GPS. OUR LIMITED DOWN TIME WAS CAUSED ALMOST EXLUSIVELY BY POWER AND AIR CONDITIONING PROBLEMS.
2. FOR THE SECOND MONTH IN A ROW THE BASEMONTHLY POWER OUTAGE (FOR BASE CONSERVATION PROGRAM AND GRID MAINTENANCE) DID NOT GO AS PLANNED. WE WERE TOLD POWER WOULD BE OFF FROM 0830-1030, BUT THE BASE PULLED THE PLUG AT 0730. WE LOST THE NIGHT SHIFT'S WORK EFFORTS, AND IT TOOK MANY ADDITIONAL MANHOURS OF EFFORT TO REINPUT THE DATA. ALSO, VOLTAGE FLUCTUATIONS ON THREE OCCASIONS DURING THE MONTH FORCED US TO SHUT DOWN THE GPS FOR A TOTAL OF NINE HOURS. ON EACH OCCASION, THE BASE

PAGE 2
WAS OPERATING ON BACKUP GENERATORS. SINCE THE GENERATORS CANNOT BE RELIED ON TO PRODUCE STABLE POWER, WE WILL NOT OPERATE THE GPS WHEN THE BASE IS USING THEM.
3. AIR CONDITIONING PROBLEMS ON TWO OCCASIONS RESULTED IN EXCESSIVE HEAT BUILDUP AND REQUIRED SHUT DOWN OF THE GPS FOR SIX HOURS. IN BOTH CASES, THE COMPRESSORS RELAYS HAD TO BE SET OR REPLACED BY CE.
4. MINOR EQUIPMENT PROBLEMS ON THE GPS (OCI'S) AND AIRCRAFT (DISC DRIVES) RESULTED IN LIMITED OUTAGES ON THE GPS.
5. FROM 8-12 MARCH, A GROUP OF EXPERTS FROM DET 2, XPZA, DOSL AND E-SYSTEMS VISITED THIS UNIT TO EVALUATE OUR PERCEIVED RECURRING MISSION PREPARATION PROBLEMS. THE TEAM LOOKED AT OUR WORK ENVIRONMENT, LEVEL OF EXPERIENCE OF PERSON EL AND PROCEDURES AND MADE SEVERAL RECOMMENDATIONS WHICH WE HAVE ADOPTED. A COPY OF THEIR REPORT WILL BE SENT TO EACH BLK III UNIT, ALONG WITH A LIST OF FOLLOW-UP ACTIONS PERFORMED BY DOY. WE ARE ALSO SENDING ALL BLK III UNITS A COPY OF OUR LATEST MCR REQUESTING 511X1S FOR CSOS, AS SUGGESTED BY THE EXPERTS.

atch 3

M/RF

R 190520Z APR 82 25 MDC(DO AND LG) ALT VIC CSC

TO RUQVAAF/HQ ESC KELLY AFB TX//DOSEC//
INFO RUQVAAF/HQ ESC KELLY AFB TX//LGMP//
RUQVAAL/AFCSC KELLY AFB TX//EII//
BT
UNCLAS E F T O
SUBJ: EQUIPMENT INSTALLATION SCHEME (EIS) CHANGE, PROJECT 200233
REF: MEIS PROJECT 200233
1. REQUEST THE POWER SUPPLY IN RACK C OF POSITION POEI BE INSTALLED BELOW THE RO-361 OSCILLOGRAPH IN PLACE OF THE BOTTOM BLANK SEVEN INCH PANEL.
2. JUSTIFICATION: PREVIOUSLY THE POWER SUPPLY WAS POSITIONED BELOW THE RO-361 BECAUSE THE HEAT GENERATED BY THE OSCILLOGRAPH CAUSED OVERHEATING PROBLEMS. INSTALLING THE POWER SUPPLY NEAR THE BLOWERS WOULD ALLEVIATE THIS PROBLEM. ADDITIONALLY, WHEN MULTIPLE SHOTS ARE PERFORMED IN RAPID SUCCESSION, THE POWER SUPPLY CIRCUIT BREAKER WILL TRIP TO THE "OFF" POSITION. IN CASES WHEN QUICK OPERATOR RESPONSE IS REQUIRED IN RESETTING THE CIRCUIT BREAKER IT IS ESSENTIAL THE POWER

PAGE 02
SUPPLY BE LOWERED TO WHERE THE OPERATOR CAN EASILY REACH THE BREAKER.
3. THIS IS AN LGM/DOU COORDINATED MSG.
BT
#1329

DC2
1E

	ACTION	INFO
LGM		
LGMP		✓
LGMP		
LGMT		
LGMP		
LGMA		

NNNN

atch 4

M/RF

HALT REPORT NR Ø16

1. 151710Z APR 82
2. RUNLIGHT WAS NOT LIT
3. DUE TO APPARENT POWER FLUCTUATION,THE WHOLE KEYBOARD LOCKED AND THE PP 7576/G (REGULATED POWER SUPPLY) REGISTERED APPROXIMATELY 3 VOLTS. POWER SWITCH WAS TURNED OFF FOR APPROXIMATELY 5 SECONDS AND TURNED BACK ON, PP7576/G THEN REGISTERED APPROXIMATELY 5 VOLTS.
4. WE THEN PROCEEDED TO REBOOT THE SYSTEM, AND ALSO OBTAINED A "DUMP ANALYSIS" PAGEPRINT READOUT FOR MAINTENANCE. EVERYTHING TOOK THE FIRST TIME AROUND AND RAN A TIPPER TEST ON BOTH LINKS.
5. N/A
6. 151758Z APR 82 SYSTEM WORKING FINE;ANALOG BACKUP AVAILABLE.

atch 5

15 MDC ALT VIC

FM ESG//CCX//
TO HQ ESC//DE/DO/LG/XP//

	ACTION	INFO
LGM		
LGM-D		
LGMF		
LGMQ		
LGMG		
LGMA		

SECTION 01
SUBJ: UTILITIES WORK IN THE (U)

OMIT

2. (U) SCOPE OF CHILLED WATER SYSTEM WORK: THE MAINTENANCE PEOPLE WILL BE ADDING A NEW BRANCH LINE TO THE CHILLED WATER DISTRIBUTION SYSTEM. THIS WORK WILL NECESSITATE: THE MAIN CHILLERS WILL BE SHUT DOWN; THE CHILLED WATER SUPPLY/RETURN LINES WILL BE DRAINED; THE SUPPLY/RETURN MAINS CUT; THE NEW BRANCH LINES WELDED IN PLACE; AND, THE LINES REFILLED AND BLED, AS NECESSARY.
3. IMPACT ON RD ESG SPACES: THE SHUT DOWN OF THE CHILLED WATER SYSTEM WILL AFFECT EQUIPMENT COOLING IN ROOMS ANTICIPATE HEAT BUILD UP IN THESE AREAS THAT WOULD REQUIRE THE TEMPORARY SHUT DOWN ON NON-ESSENTIAL EQUIPMENT. COMFORT COOLING WILL CONTINUE TO BE SUPPLIED, BUT BY OUTSIDE AIR ONLY. OF ADDITIONAL CONCERN TO US IS THE COMM CENTER. HEAT BUILD UP IN THAT AREA COULD AFFECT OPERATIONS.
4. ACTIONS THAT WILL BE TAKEN, ON , TO LESSEN THE IMPACT OF THE WORK:
A. (U) THE MAINTENANCE PEOPLE WILL:

OPS 5
OPS 3 DCS

M/X/RF atch 6

(1) (U) ADJUST THE APPROPRIATE DAMPERS IN THE COMFORT COOLING AIR DISTRIBUTION SYSTEM TO ENSURE THAT 100 PERCENT OUTSIDE AIR IS PROVIDED THROUGHOUT THE BLDG. THE PRESENT NIGHT-TIME TEMPS ARE DROPPING TO THE LOW-40'S OR UPPER-30'S, SO COOLING CAN BE PROVIDED.
(2) (U) TURN OFF ELECTRIC REHEAT COILS RH-41, RH-42, RH-43 AND RH-45, DURING THE WORK PERIOD. THESE COILS ARE IN THE COMFORT COOLING AIR DISTRIBUTION SYSTEM FOR OUR AREAS. KEEPING THE REHEAT COILS OFF WILL ENSURE THAT THE COLDEST POSSIBLE AIR IS PROVIDED. THIS IS EXTREMELY IMPORTANT, SINCE IT WILL BE THE ONLY SOURCE OF COOL AIR, AS THE CHILLED WATER TO THE EQUIPMENT COOLING AIR HANDLING UNITS (AHU) WILL BE OFF.
(3) (U) KEEP BLOWERS ON, IN AHU-12, AHU-13 AND AHU-15. THESE AHU'S PROVIDE EQUIPMENT COOLING IN OUR SPACES. ALTHOUGH THE CHILLED WATER TO THESE AHU'S WILL BE OFF, THEY WILL STILL BE USED TO CIRCULATE AIR TO COOL EQUIPMENT, AS MUCH AS POSSIBLE.
B. ESG/DO WILL TAKE THE FOLLOWING ACTIONS DURING THE THE WORK PERIOD\
(1) PARTIALLY SHUT DOWN.\ . RECEIVERS WILL BE KEPT UP, MANNED, AND THE APPROPRIATE FREQUENCIES MONITORED. THIS WILL ALLOW US TO REDUCE THE USE OF ROOM , THUS LOWERING THE COOLING LOAD.
(2) SHUT DOWN THE . THIS PIECE OF EQUIPMENT GENERATES A SUBSTANTIAL AMOUNT OF HEAT. KEEPING IT INACTIVE, TEMPORARILY, WILL ALSO REDUCE THE AMOUNT OF COOLING REQUIRED.
(3) WE WILL ATTEMPT TO REDUCE USE TO ONE SCOPE, IF POSSIBLE. WE WILL BE PREPARED TO BRING UP ADDITIONAL SCOPES, IF THE MISSION DICTATES.
(4) (U) ENSURE THAT BACK UP COMM EQUIPMENT IS OFF.
(5) ([redacted]) TEMPORARILY SUSPEND SERVICE VIA SEVERAL COMM CIRCUITS. CUSTOMERS/SUPPLIERS WILL BE ADVISED OF THE SUSPENSION OR ASKED TO SUSPEND TRANSMISSIONS DURING THE WORK PERIOD. CIRCUITS THAT WILL BE AFFECTED ARE:

(6) SHUT DOWN POSITIONS NOT IN USE, I.E., CONTINGENCY AND POSITIONS (ONE-EACH).
(7) (U) REDUCE LIGHTING IN ROOMS , AS MUCH AS POSSIBLE, WITHOUT INHIBITING MISSION PERFORMANCE AND SAFETY.
(8) (U) RESTRICT THE USE OF APPLIANCES (COFFEE POTS, REFRIGERATOR MICROWAVE, ETC.).
(9) BE PREPARED TO ACTIVATE/USE ALTERNATE COMMS, IF IS AFFECTED.
(10) (U) PROVIDE PRIOR NOTIFICATION TO APPROPRIATE AGENCIES OF THE WORK THAT WILL BE DONE, AND THE MISSION IMPACT.
C. (U) ESG/LG WILL TAKE THE FOLLOWING ACTIONS DURING THE WORK PERIOD, ON
#7604

FINAL SECTION OF 02

(1) (U) HAVE ONE MAINTENANCE MAN FROM EACH SHOP AVAILABLE TO HANDLE EMERGENCIES, IF THEY ARISE.
(2) (U) SHUT DOWN LIGHTING IN ROOM , WITHIN THE LIMITS OF SAFETY.
(3) (U) ENSURE THAT MAINTENANCE PERSONNEL FAMILIAR WITH HOT/COLD START PROCEDURES FOR ARE ON HAND.
D. TH COMM GROUP WILL TAKE THE FOLLOWING ACTIONS DURING THE WORK PERIOD
(1) (U) SHUT DOWN NON-ESSENTIAL EQUIPMENT.
(2) (U) SHUT DOWN HEAT GENERATING APPLIANCES.
(3) (U) REDUCE LIGHTING WITHIN THE LIMITS OF SAFETY.
(4) OPERATE AS LONG AS THE AMBIENT TEMP ALLOWS. IT IS ANTICIPATED THAT PROBLEMS MAY DEVELOP WHEN THE TEMP IN THE COMM CENTER REACHES 82-85 DEGREES F.
(5) (U) NOTIFY APPROPRIATE AGENCIES SHOULD A OUTAGE OCCUR.
E. (U) OTHER:
(1) (U) INSTALLERS HAVE BEEN ASKED TO SUSPEND WORK FROM 1600, THRU 0800.
(2) (U) TEMPERATURE IN OUR SPACES WILL BE CLOSELY MONITORED AND APPROPRIATE ACTIONS WILL BE TAKEN, IF HEAT BUILD UP BECOMES EXCESSIVE.

/// UNCLAS E F T O ///

LGM	ACTION	INFO
LGM-D		
LGMP		✓
LGMM		
LGMG		✓
LGMA		

R 130110Z APR 82 50/DE DO LG XP ALT VIC
FM ESG//CCX//
TO HQ ESC//DE/DO/LG/XP//

INFO HQ ESP//XO//
ZEM
UNCLAS E F T O
SUBJ: UTILITIES WORK IN THE AFTER ACTION REPORT
REF: MY 070210Z APR 82
1. UTILITIES WORK WAS ACCOMPLISHED IN THE 11 - 12 APR 82, AS SCHEDULED. OUR PLAN TO COPE WITH THE SITUATION (AS OUTLINED IN THE REF MESSAGE) WAS IMPLEMENTED, AND THE IMPACT ON THE UNIT/MISSION WAS MINIMAL.
2. SIGNIFICANT EVENTS WHICH OCCURRED ON 11 APR 82:
A. AIR CONDITIONING WORK WAS DONE FROM 0630-1030L. THE MAINTENANCE PEOPLE HAD SOME MINOR PROBLEMS WITH THE WELDS ON THE PIPES. THIS EXTENDED THE PERFORMANCE PERIOD BY 30 MINUTES, BUT DID NOT ADVERSELY IMPACT US.
B. AT ABOUT 0730L, A MOMENTARY (LESS THAN 10 MINUTES) OUTAGE WAS EXPERIENCED. THE CAUSE OF THE OUTAGE MAY HAVE BEEN DUE TO THE HEAT BUILD UP, OR A NON-HEAT RELATED EQUIPMENT MALFUNCTION, OR A COMBINATION OF BOTH. DEFINITE CAUSE CANNOT BE ESTABLISHED.
C. ALTHOUGH THE INTERNAL CABINET TEMP ON ROSE TO 90 DEGREES, NO PROBLEMS WERE EXPERIENCED.
D. CHILLED WATER SERVICE WAS RESTORED AT APPROX 1030L. WITHIN 30 MINUTES, ALL NORMAL MISSION EQUIPMENT WAS ON LINE. TEMP IN THE CABINET HAD DROPPED 5 DEGREES, IN THAT TIME.
3. SIGNIFICANT EVENTS ON 12 APR 82:
A. SWITCH FROM UNINTERRUPTED POWER SUPPLY (UPS) TO COMMERCIAL POWER TOOK PLACE AT ABOUT 0730L.
B. UPS POWER WAS RESTORED AT ABOUT 1130L. THE COORDINATION AT THE TIME OF THE SWITCHOVER WAS POOR, AND A 26 MINUTE COMM OUTAGE WAS EXPERIENCED. THEREAFTER, NO POWER PROBLEMS.
C. STREAMLINER OPERATIONS UNAFFECTED.
#4260

DE
DO
LG
XP MKF

/// UNCLAS E F T O ///
atch 7

R 291305Z APR 82 5Ø/LG ALT VIC

LG 3144/41

TO HQ ESC//LGMG//
INFO HQ ESC//LG//

ZEM
UNCLAS E F T O
SUBJ: MB-18 STATUS
1. WORK ACCOMPLISHED ON OLD MB-18 DIESEL GEN:
A. TEMP. FIX ON THE STARTER UNIT (NEEDS TO BE REPLACED).
B. ADJUSTED ELECTRONIC GOVERNOR CONTROL BOX.
C. REDUCED OVER FILLED OIL LEVEL.
D. REPLACED 1 1/2 QUARTS OF OIL.
E. LOAD TESTED GEN. AT 1ØØ PERCENT LOAD WITH 8Ø PERCENT CURRENT TEST COMPLETED NO DISCREPANCIES NOTED.
F. RECHARGED BATTERIES TO FULL CAPACITY.
G. REPLACED FUEL POD CONNECTION ON A1B FUEL TRAILER.
2. WORK ACCOMPLISHED ON NEW MB-18 DIESEL GEN:
A. REINSTALLED CHARGED BATTERIES.
B. AFTER ADJUSTING THE VOLTAGE SENSING CARD IT WAS FOUND TO BE MALFUNCTIONING. TO FACILITATE TESTING AND OPERATION OF THE MB-18 THE VOLTAGE SWITCHING CARD WAS REMOVED (REMOVES OVER/UNDER VOLTAGE PROTECTION)
C. LOADED THE GEN 1ØØ PERCENT LOAD AND 8Ø PERCENT CURRENT AND RAN THE GEN FOR A 3 HR TIME PERIOD, TO BURN OUT CARBON AND BURN IN RINGS.
D. REPAIRED BAD BATTERY CABLE.
E. CHECKED ALL FLUID LEVELS AFTER BREAK-IN WAS COMPLETE. ALL LOOKED GOOD AND NO REPLACEMENT OR REFILL WAS NEEDED.
3. FOLLOWING ITEMS NEED TO BE ORDERED. (REFERENCES AND PN'S IDENTIFIED TO PERSONNEL).
A. OLD MB-18:
(1) RADIATOR CAP
(2) STARTER UNIT
B. NEW MB-18:
(1) VOLTAGE SENSING CARD
(2) LATCH PADDLE
(3) RETAINER, WASHERS
(4) SCREW, SLOTTED HEAD.
4. THE OLD MB-18 IS OPERATIONAL AT FULL CAPABILITY WHILE THE NEW MB-18 IS AT LIMITED SERVICE.
5. RECOMMENDATIONS BY WILL BE FORWARDED NLT COB 30APR82.
#2573

THIS IS WORK BEING DONE AT A MOBILE UNIT THAT HAS BEEN DEPLOYED FOR OVER 90 DAYS.

atch 8

Cy to M

APPENDIX D

RELATIONSHIP OF CONDITION MONITORING AND TESTABILITY WITH OTHER DISPLINES

- R. R. HOLDEN (UNPUBLISHED PAPER)

APPENDIX D

RELATIONSHIP OF CONDITION MONITORING AND TESTABILITY WITH OTHER DISCIPLINES

The maintenance of direct interactions with other disciplines such as reliability, maintainability, testability, and system design is the essential element in the development of a superior condition monitoring program. Inclusion of check sheets and other aids in the collection and analysis of data, can help ensure that these interactions are effective.

The accompanying table outlines condition monitoring, testability and other design disciplines/relationships and some of the more significant impact areas. Maintaining timely, dynamic relationships with other disciplines is most necessary in the development of a superior program. Close coordination and cooperation between the practitioners of the various disciplines, with frequent and timely consultations, is required to keep all elements in perspective. Aids and check sheets provide significant assistance in the collection and analysis of data.

Of great importance is the interface with system and subsystem design engineers in the applications of complex test/diagnostic technologies for electromechanical condition monitoring applications. This aspect will take on ever-increasing importance as existing and new technologies provide even more complex hardware. Detailed planning is essential to ensure availability of the test/diagnostic capabilities

that will be required in the future development, production, deployment, and operation of C^3I systems. Specific effort is required to identify, analyze, and select methods for testing and monitoring these complex devices and ensuring that test/ monitoring aids are incorporated into assemblies that use them.

In addition to the relationship between reliability and test/diagnostic allocations, monitoring aspects must directly consider failure modes/effects and critical items. The same quality effort expended for complex Prime systems must be applied to system critical electro-mechanical performance and condition. This consideration keeps the emphasis on system engineering where it belongs, because it emphasizes elements critical to total system capability and availability.

Probably the major impacts occur between maintainability and test/monitoring because of their very close interdependence. In many respects both consider the same elements but in different aspects. Some measures of test/diagnostic ability are also measures of maintenance actions, particularly time-to-fault-detect and time-to-fault-isolate. Because of this close relationship, a substantial study effort expended in identification and analysis should establish the timely test/diagnostic approaches and determine means of achieving the greatest testability/maintainability condition monitoring synergism. Availability is also directly impacted by these disciplines because of the need for and consumption of system time to perform test/diagnostic/maintenance actions. Hence, availabililty is a prime study consideration.

The logistics system and condition monitoring have a number of points of interface, the more important being availability of support facilities and equipment, life-cycle and design-to-cost aspects, supportability characteristics, and the maintenance plan. The specific areas of impact and interaction must be established so that recommendations and procedures to minimize interaction and maximize the effectivenss of all disciplines can be determined. The important point is to keep primary emphasis on the system function, maximized over the system life.

Definition and resolution of the interdisciplinary problems between condition monitoring, testability and interfacing disciplines is a major concern of the condition monitoring study. It is only in this manner that the diagnostic test and monitoring discipline can be defined and placed in proper system aspect relationship to other design disciplines. Close personal interfacing (*"eyeball-to-eyeball"* contact) is needed to maintain perspective. This will keep condition monitoring progressing toward the common goal of lifetime system effectivness while it yet maintains significant impact.

<u>Testability Definition</u> - Testability may be regarded as the capability of an entity to receive valid, dependable functional testing and associated fault detection/isolation, within constraints of elapsed time, complexity of access, equipment and functional procedures, and within limits of manpower, material, and other test resources. The tested entity may be any level of indenture of a

system of prime mission equipment or of some tangible element of mission support. Table I expresses this concept and its relation to condition monitoring.

Test/Diagnostic Objectives - Functional test and condition monitoring are necessary to give assurance and expectation of mission success preparatory to or during operation, and in the course of maintenance or repair. Malfunction detection is necessary to permit consideration of alternative modes of operation and degree of mission success to be expected, together with enabling decisions to conduct maintenance with or without system shutdown. Isolation of malfunctions is a prerequisite to effecting repairs or otherwise restoring degraded components to required levels of operating performance.

Testability Requirements - Table II summarizes testability requirements. Testability characteristics must be injected early into designs. Poor testability conditions comprise design flaws. Hence, they will lead to expensive design change procedures if not recognized before design freeze, anywhere in the development flow. This need for identification and resolution applied from the inception of conceptual studies, through validation, engineering development, full scale development, production and the deployment phases. Testability is subordinate to performance, but system performance, to be effective, efficient, and economical, requires testability in design.

TABLE I. TEST AND DIAGNOSTIC CHARACTERISTICS

Test/Diagnostic Aspect	Significance
• Thoroughness and ease of - Condition Monitoring - Fault Detection - Fault Isolation - Functional Verification	• Testing is essential to full system effectiveness • Operators need to know the status system operating modes with full assurance • Valid, accurate, unambiguous detection and isolation of faults are key to achieving maximum operational availability • Functional test is a necessary validation of system restoration by maintenance
• Constraints of - Elapsed time - Simplicity of access - Human resources - Test materials - All cost-gathering elements	• Test and diagnostic discipline in all aspects has heavy influence on the costs of operating and supporting prime mission equipment systems

Test/Diagnostics in Life Cycle Phases - Degradation may occur at any point in the life cycle of a maintenance entity, beginning with the initial fabrication or forming of single components. Test/Diagnostics therefore need to be provided at the various stages of fabrication and assembly, and at the various steps of integrating assemblies into LRUs, into units, into equipments and into systems. Furthermore, testability is a feature needed to ease and simplify acceptance and demonstration, to monitor deployed performance, and to detect, locate and isolate faults.

Test/Diagnostic Economics and Impacts - Effective testability is, of course, an expense item, but lack of an effective test/diagnostic capability is an expense item of much greater magnitude. The MTTR term in the classical formulation of inherent availability,

$$A_1 = (MTBF)/(MTBF + MTTR)$$

is a fundamental indicator of the cost impacts of testability characteristics in design. Poor testability characteristics cause extended MTTR, with the direct impact of lost availability. Further, extended MTTR clearly implies the added remedial expenditures of costly manpower and test and diagnostic resources.

TABLE II. TEST/DIAGNOSTIC CAPABILITY INTERFACES WITH OTHER DISCIPLINES

Discipline	Testability Relation
• Reliability	- Failure rates - test rates allocations - Critical areas - thoroughness of test/ diagnostics
• Maintainability	- Allocation of access to test/diagnostic indicators - MTTR allocations - Functional design for maintainability - Functional design for test/diagnostic capability
• Design	- Condition Monitoring Techniques - Accommodation of reliability/ maintainability requirements - Design/BIT ratio allocation
• Availability	- Test/troubleshooting time allocation - Scheduled vs unscheduled testing concept
• Life-cycle cost/ design-to-cost	- Costs of alternative test/diagnostic approaches
• Supportability	- Compatibility of test/diagnostic approach alternatives with logistic support practices of procuring/using agency

TABLE II. TEST/DIAGNOSTIC CAPABILITY INTERFACES WITH OTHER DISCIPLINES

(Continued)

Discipline	Testability Relation
• System Test	- Coordinate system performance test concept with maintenance test/diagnostic concept
• Management	- Recognition of test/diagnostic capability as a program element
	- Need for management exception trigger levels and allocation

APPENDIX E

DIESEL GENERATORS MANAGED BY S-ALC/MMIRM

APPENDIX "A"
PART I

FIIN DESIGNATOR TO STOCK NUMBER WITH MODEL NUMBER

ALPHA NUMERIC CODE	FIIN	MODEL
AAA	6115-022-3839	PU705
AAB	6115-877-9586	JHGW5A(MOD)
AAC	6115-144-8087	B6B
AAD	6115-086-7444	305CCK
AAE	6115-144-8089	C13A
AAF	6115-149-0890	PE215C
AAG	6115-067-5188	MB5S
AAI	6115-821-7746	2H4815(D364)
AAJ	6115-822-2718	1L2200(D364)
AAM	6115-844-2052	PU286G
AAN	6115-069-2852	LG-10
AAV	6115-990-3208	8D28-9
AAW	6115-156-0297	C13
AAZ	6115-156-0306	B6A
AA2	6115-925-5746	TM4900
AA3	6115-920-2390	D333
AA4	6115-920-2402	30DEF
AA5	6115-156-0311	F3
AA7	6115-944-1915	TM4156
ABB	6115-950-6930	54100-60
ABD	6115-951-8736	20K.W. PP
ABE	6115-079-2700	MB19W
ABG	6115-999-2659	MB5A
ABH	6115-017-8238	MEP021A
ABK	6115-228-5815	PE75
ABL	6115-228-5818	PE210B
ABO	6115-230-4001	PE197
ABP	6115-230-4002	PE214
ABR	6115-235-8666	15800
ABV	6115-236-8673	WGD3012
ABW	6115-235-8674	5JWC1E
ABZ	6115-235-8682	BD15A3CE
AB2	6115-235-8683	DA60A3CE
AB6	6115-920-2387	D330
AB7	6115-236-9990	RD6A
AB8	6115-236-9993	DC100A3CE
AB9	6115-236-9994	D13000
ACA	6115-236-9995	RD6A12
ACB	6115-236-9996	D397
ACJ	6115-237-0228	1A21
ACM	6115-075-1639	GTGE70-6
ACN	6115-914-3444	EMU-17
ACO	6115-920-2452	15DEC
ACT	6115-017-8240	SF.5.MOD
ACR	6115-237-3004	RD14A12
ACU	6115-237-3013	RD6A
ACW	6115-237-3017	4GD605
ACY	6115-967-4482	MB-5B
ACZ	6115-237-3022	RD14A
AC4	6115-237-3026	6016E
AC8	6115-237-3032	PE207A
ADB	6115-937-3523	MB5A/S
ADC	6115-241-8486	EC51
ADE	6115-241-8488	6GD605
ADH	6115-984-8749	20KWSYS
ADI	6115-931-5796	GTGE-30-18(MOD)
ADK	6115-081-2036	MB-15
ADM	6115-241-8499	15700
ADN	6115-914-3445	EMU-16
ADQ	6115-949-0571	EMU-12E
ADR	6115-950-1351	UPS60-60
ADS	6115-950-1352	UPS60-100
ADU	6115-017-8237	SF.30.MD
ADV	6115-723-3367	STRIC-EMU-12
AD3	6115-920-2383	57870
AEB	6115-542-6011	JSGA-601
AEC	6115-940-7867	DC.05.MD
AED	6115-116-2216	EMU-20
AEE	6115-920-2386	S6701
AEG	6115-243-7728	JB5AC
AEI	6115-758-5492	GTGE-70-9-1
AEJ	6115-912-8556	GTGE-30-18A
AEL	6115-928-3060	DW150AC
AEO	6115-464-9441	EMU-16/W
AEQ	6115-243-7747	1942A
AER	6115-243-7748	DT30A3CE
AEU	6115-244-5021	RD14A
AEV	6115-881-5170	1P312
AEW	6115-734-4704	EMU-14
AEY	6115-118-7646	EMU-21
AFA	6115-964-3040	EMU-19U
AFE	6115-245-2531	52MPK4
AFF	6115-126-3024	EMU-30
AFG	6115-914-3447	EMU-18
AFI	6115-116-2219	EMU 24U
AFM	6115-918-8527	EMU-28
AFN	6115-912-4730	EMU-15
AFS	6115-420-8486	M32A-60A
AFT	6115-929-9892	DW100
AFW	6115-116-2217	EMU-22E

APPENDIX "A"
PART I

FIIN DESIGNATOR TO STOCK NUMBER WITH MODEL NUMBER

ALPHA NUMERIC CODE	FIIN	MODEL	ALPHA NUMERIC CODE	FIIN	MODEL
AFX	6115-081-2395	EMU-25E	AII	6115-464-9440	EMU-15/W
AFY	6115-116-2218	EMU-23E	AIO	6115-500-0085	(PU308)
AF3	6115-329-3580	G1	AIP	6115-500-0140	JWC4108
AF4	6115-329-3581	2200/MB2	AIQ	6115-500-0287	C22C
AF5	6115-329-3582	PE185A	AIR	6115-958-6905	EMU-11U
AF6	6115-329-3583	MB3	AIS	6115-719-6122	EMU-10MS
AF7	6115-329-3584	LGA601-100	AIT	6115-500-0614	4002
AF8	6115-329-3585	D17000E	AIU	6115-500-0993	100DAW
AF9	6115-329-3586	3H8600(D364)	AIV	6115-500-1181	M100DM6
AGA	6115-081-2032	MB-15	AIW	6115-081-2030	MB16
AGC	6115-329-3589	C25	AIX	6115-678-6311	MB19
AGD	6115-329-3593	EG110	AIY	6115-081-2034	MB17
AGE	6115-329-3594	G1028	AIZ	6115-081-2035	MB19
AGF	6115-329-3595	C21	AI2	6115-500-2328	B11
AGG	6115-329-3596	C21A	AI3	6115-500-2548	HRU28A
AGH	6115-329-3597	C22A	AI4	6115-500-4001	V32D21
AGJ	6115-329-3600	A7	AI5	6115-500-4011	V32D2
AGK	6115-329-3602	B10A	AI6	6115-500-4772	EA536
AGL	6115-329-3603	B10	AJA	6115-504-1401	MB5
AGM	6115-329-3605	C26	AJB	6115-504-1443	EG105
AGN	6115-329-3606	C26B	AJC	6115-504-2038	C7AB
AGO	6115-329-3970	B10B	AJD	6115-081-2031	MB-18
AGP	6115-346-2743	A3A	AJE	6115-506-8801	MB-11
AGQ	6115-351-9104	15US10327A	AJH	6115-523-5499	DG-25
AGR	6115-126-3025	A/E 24U-8	AJI	6115-523-5500	258G906000
AGT	6115-067-5186	2CCK/IRV3	AJJ	6115-526-0114	PU361
AGY	6115-738-6342	30KW-SYS	AJK	6115-535-4431	MB1
AG4	6115-052-2422	MARK-3	AJL	6115-535-4432	40EX8
AG5	6115-371-7651	6KW	AJM	6115-536-8997	EG101
AG6	6115-371-7652	5US10285A	AJN	6115-538-8629	C26
AHA	6115-126-3026	A/E 24U-9	AJO	6115-538-8647	A210
AHB	6115-998-8872	54100-150A	AJP	6115-538-8727	RD24A12
AHG	6115-376-6985	6903	AJQ	6115-893-9098	PU377
AHI	6115-376-6988	1877	AJR	6115-834-7132	TM3073
AHO	6115-376-7001	5ABG4M311A	AJS	6115-542-6042	D375
AHP	6115-376-7003	CE100ACWK4	AJU	6115-542-6833	PU26
AHQ	6115-376-7006	GGC30AC	AJV	6115-546-2145	PU211G
AHT	6115-937-4389	60KW, P.S.	AJW	6115-542-6083	26800
AHU	6115-376-7017	1780	AJX	6115-546-2147	2C000
AHW	6115-126-3029	EMU-29E	AJ6	6115-548-1382	C21B
AHY	6115-951-3622	7163	AJ8	6115-548-1384	B12
AIA	6115-056-6812	C26M	AJ9	6115-548-1385	B10B
AIB	6115-955-4254	4199	AKD	6115-118-1241	MEP-004A
AIC	6115-056-6813	C26BM	AKE	6115-127-8544	C26C
AIE	6115-392-8191	SCD22287	AKF	6115-897-5704	MC4

FIIN DESIGNATOR TO STOCK NUMBER WITH MODEL NUMBER

ALPHA NUMERIC CODE	FIIN	MODEL
AKG	6115-553-8957	MD3A
AKI	6115-847-2746	PU362IM
AKK	6115-118-1243	MEP-006A
AKL	6115-557-8113	MB19 (4031)
AKM	6115-561-2004	EA536M
AKN	6115-133-9104	MEP-009A
AKO	6115-578-6358	EA536M
AKP	6115-583-9365	M32A-13
AKQ	6115-990-2465	MB-16
AKR	6115-990-2464	MB-18
AKS	6115-617-1417	M2
AKT	6115-594-6816	TM76B
AKU	6115-539-9952	CE100ACWK4M
AKW	6115-628-0245	C1B
AKX	6115-624-0385	4060
AKY	6115-118-1247	MEP-104A
AKZ	6115-635-1253	M60DA6W
AK2	6115-635-1254	M10GCTSH4
AK3	6115-133-9102	MEP-106A
ALA	6115-843-8501	MD3M
ALD	6115-635-1520	DID3061
ALE	6115-118-1240	MEP-005A
ALG	6115-635-2261	120GS
ALH	6115-133-9101	MEP-007A
ALK	6115-635-2272	M100DA8W
ALL	6115-635-2273	NHRSGA601-100
ALN	6115-118-1245	MEP-103A
ALO	6115-118-1252	MEP-105A
ALP	6115-935-8729	MEP-108A
ALS	6115-635-2528	SS110W
ALT	6115-635-2529	NHRSGA601-150
ALU	6115-621-2928	ALEX-1
ALW	6115-635-2829	1860
ALX	6115-635-3845	MB13
AL2	6115-635-5595	MD-3
AMB	6115-635-6650	ED15
AMF	6115-975-5381	J[illegible]W3C
AMH	6115-950-6175	150 KW, P.P.
AML	6115-[illegible]	[illegible]-17/W
AMN	6115-635-6340	[illegible]10AC
AM[illegible]	6115-9[illegible]-3039	572.000
[illegible]	6115-[illegible]	[illegible]
[illegible]	6115-[illegible]	2405
[illegible]	6115-[illegible]	PE85A,B
[illegible]	6115-[illegible]	PU173U

ALPHA NUMERIC CODE	FIIN	MODEL
AM2	6115-635-8140	4BDG182
AM6	6115-635-8580	CE60GA
AM9	6115-635-8594	CE50
ANB	6115-635-8598	D1697
ANC	6115-839-4055	JHGW5A
ANF	6115-464-9443	EMU-18[illegible]W
ANG	6115-882-8612	15HC3FE-2339F
ANI	6115-724-8455	26300
ANK	6115-841-0678	EG615
ANM	6115-890-0379	LF311
ANN	6115-767-7714	MX-7825
ANP	6115-719-6127	EMU 11ES
ANT	6115-928-7652	197-0030
ANU	6115-643-1208	20AM
ANV	6115-643-3827	30US10236A
ANX	6115-643-3981	4907A
AN3	6115-643-4496	A3
AN4	6115-643-4499	A1
AN5	6115-995-6784	PU587M
AN6	6115-088-4461	EMU9M
AOB	6115-792-2541	5114
AOE	6115-694-5159	4820
AOH	6115-810-5256	PU361A
AOJ	6115-697-2417	PE95G,E,I
AON	6115-096-7296	PU24BU
AOY	6115-768-1780	CL30-1
AO6	6115-245-0525	6905
APE	6115-809-6815	PU286G/M
APG	6115-810-5257	PU361B
APJ	6115-950-7677	PU597G
APK	6115-893-8202	25SN9-139
APL	6115-643-1209	4002N
APN	6115-828-4463	DASE415-150
APQ	6115-845-5675	D342C
AP2	6115-017-8236	CE-0172C
AQC	6115-950-4551	PE95K/TM
AQD	6115-064-1364	PE95K/TM
AQE	6115-064-2883	PE95K/TM
AQL	6115-088-0368	PE95G,E,I/TM
AQO	6115-738-6339	PU619/M
AQP	6115-990-2466	PU581
AQS	6115-798-3444	6910A
ARB	6115-836-0734	ANGJQ-6
ARD	6115-952-1939	GTCE30-13
ARE	6115-017-8239	MD-28-DC

ALPHA NUMERIC CODE	FIIN	MODEL
ARF	6115-738-6340	PU620/M
ARK	6115-837-5049	PU594
ARL	6115-837-5047	PU595
ARM	6115-064-8168	J-85-60
ATB	6115-376-7120	19100
ATF	6115-081-2033	MB17
AWA	6115-225-7663	M32A-60
AWF	6115-778-6005	CE106ACWK6
AXA	6115-883-1215	M32A-10
AXB	6115-690-4037	2C000M
AXC	6115-628-1243	CE55ACWK6
AXE	6115-617-1545	LGA601-100M
AXF	6115-063-9983	EMU2E
AXG	6115-984-4769	EMU4E
AXH	6115-724-3651	EMU6E
AXI	6115-027-0820	EMU5E
AXJ	6115-950-6172	EMU3F
AXL	6115-088-8356	CE55ACWK6
AXM	6115-812-1741	MB-15
AXN	6115-812-1742	M32A-12
AXO	6115-631-6811	CE105ACWK8
AXQ	6115-847-1578	JHGW5A
AXS	6115-951-8735	EMU8E
AXV	6115-504-0144	PE95K
AXW	6115-508-2526	PE95K
AXX	6115-632-2687	PE95K
AYT	6115-088-1889	EMU6E
AYX	6115-077-8600	CE301ACWK1

APPENDIX F

ECUs MANAGED BY SA-ALC/MMIRG

APPENDIX F. ECUs MANAGED BY SA-ALC

The following table was provided by SA-ALC/MMIRGA

USAF Type	Mfg.	NSN	Part No.	T.O.
A/E32C-9	APP	4120-00-913-3508	MIL-A-27712	
120/208-60-3	TROPIC AIR	4120-00-202-6571	A1E65	40A1-5-9-1
90,000 BTH	ITT GILFILLAN	4120-00-060-4718	101583	
7-1/2 TON	TROPIC AIR	4120-00-274-5781	ALE29	40A1-5-3-1
10/208/60-3	KECO	4120-00-827-8746	J65000	35E9-56-1,3,4
10/208/60-3	THERM AIR	4120-00-022-0398	M90A	35E9-56-11,13,14
10/208/60-3	THERM AIR	4120-00-152-0840	M90B	35E9-56-11,13,14
A/E32C-17	APP	4120-00-945-2663	MACV20	21
	TRANE	4120-00-836-9511	6700-05 F18T	35E9-116-1,3,4
208-60-3 20,000 BTH	KECO	4120-00-103-3242	82500-5	35E9-116-11,13,14
	TRANE	4120-00-442-0075	6700-06	35E9-116-1,3,4
	KECO	4120-00-142-3335	F18T2	TM5-4120-360-14
	AAF	4120-00-168-1781	CH-620-2 CE 20 VAL 6	35E9-159-1,14
	TRANE	4120-00-973-4589	6V20-3570-07	TM5-4120-222-24P
A/E32C-18	APP	4120-00-947-7104	MACH V20 6700-01	
	TRANE	4120-00-954-6512	6700-04	35E9-118-1,3,4
208-400-3	KECO	4120-00-702-0711	F18TH	35E9-118-21,23,
20,000 BTU	AAF	4120-00-089-9723	CH-420-2	35E9-118-11,13,14
	TRANE	4120-00-949-0025	4524-3510-EXT5	NON-SPEC
	SPERRY	4120-00-225-3786	2583183	
	WEDJ	4120-01-063-6830	VAF18100-400	TM5-4120-350-14 TM5-4120-350-24P
	HOTTEL	4120-00-152-1150	CV20-4-08	TM5-4120-307-15 TM5-4120-307-154P TM5-4120-307-24P
	TRANE	4120-00-061-2869	CE20VAL4	TM5-4120-222-24P
	HOTTEL	4120-01-089-4054	CV-18-4-08	TM5-4120-344-14 TM5-4120-344-24P

USAF Type	Mfg.	NSN	Part No.	T.O.
NE32C-23	APP	4120-00-944-2779	MAC4V11	
	TRANE	4120-00-929-6748	5400-3	35E9-127-11,13,14
200-400-3				
12,000 BTU				
A/E32C-24	APP	4120-00-912-8949	MAC6V40	
			5450-04	
	TRANE	4120-00-234-8501	6250-06	35E9-102-21,23,24
208-60-3	TRANE	4120-00-108-1747	5400-21(LTSU)	35E9-102-21,23,24
40,000 BTU	KECO	4120-00-702-0710	81700-1	35E9-102-31,33,34
	KECO	4120-00-147-3734	81700-9	35E9-102-31,33,34
	AAF	4120-00-849-5397	CH-640	35E9-102-11,13,14
	HOTTEL	4120-01-010-2861	CV-36-6-08-AF	35E9-102-41,43,44
	RCA	4120-01-014-4127	SOCN2377220-1	
	TRANE	4120-00-929-6747	A4524-3950	NON-SPEC 2TH USE
	KECO	4120-00-350-0184	81700-5	MARINE
	HOTTEL	4120-00-545-7265	CV40-5-6-08MC	TM5-4120-353-14
	KECO	4120-01-085-4731	F36T-2	TM5-4120-353-24P
A/E32C-25	APP	4120-00-880-2689	MAC4V40	60 SPARES
			3950-5	
			5450-2	
	TRANE	4120-00-913-8899	5450-12	35E9-102-1,3,4
208-400-3	AAF	4120-00-937-7337	CH440-1	35E9-102,11,13,14
40,000 BTU	KECO	4120-01-080-0375	81700-7	35E9-189-1,3,4
				TM5-4120-350-14
	WEDJ	4120-01-049-3567	VM36000-400	TM5-4120-350-24P
	TRANE	4120-00-444-3921	MAC4V40-	35E9-102-1,3,4
			5450-10	
	TRANE	4120-00-108-1748	5450-20 LTSUY	35E9-102-1,3,4

USAF Type	Mfg.	NSN	Part No.	T.O.
A/E32C-26	APP	4120-00-947-4765	MAC6V60	68 SPARES
	TRANE	4120-00-236-4272	MAC6V60-5859-83	35E9-117-21,13,24
208-60-3	KECO	4120-00-764-0303	80800-9-23-2	35E9-117-11,13,14
60,000 BTU	TRANE	4120-00-983-3717	4150-06	35E9-117-1,3,4
	TRANE	4120-00-911-0187	A4524-4150 EXT6	35E9-117-1,3,4
	KECO	4120-01-074-0601	80800-11	35E9-117-11,13,14
A/E32C-27	APP	4120-00-946-5545	MAC4V60	10 SPARES
	TRANE	4120-00-485-1418	5359-02	35E9-140-11,13,14
208-400-3	KECO	4120-00-702-0624	F60T4	35E9-140-1,3,4
60,000 BTU	TIERNAY	4120-01-098-6651	100484	35E9-192-1,3,4
A/E32C-29	APP	4120-00-942-3211	MAC6V11 5400-10	
	TRANE	4120-00-929-6749	6800-08	35E9-122,1,3,4
115-60-1 12,000, BTU	THERMO KING	4120-00-580-6171	75-5166	35E9-25-3,4
	TRANE	4120-00-912-3593		NON SPEC
A/E32C-30	APP	4120-00-916-9736	MAC6V20	
	TRANE	4120-00-689-8137	6700-7	35E9-144-1,3,4
230-60-1 20,000 BTU	KECO	4120-00-255-8334	907735-1	35E9-144-11,13,14
A/E32C-39	APP	4120-00-483-2880	12090-601	
54,000 BTU	AAF	4120-00-323-7780	12090-602	35E9-163-1,3,4
208-50/20-3 10,000 BTU	KECO	4120-01-075-4498	74500-1	35E9-195-1,4

AD-A138 576 CONDITION MONITORING TECHNIQUES FOR ELECTROMECHANICAL EQUIPMENT USED IN A..(U) HUGHES AIRCRAFT CO LONG BEACH CA R R HOLDEN AUG 83 RADC-TR-83-180 F30602-81-C-0113 4/4

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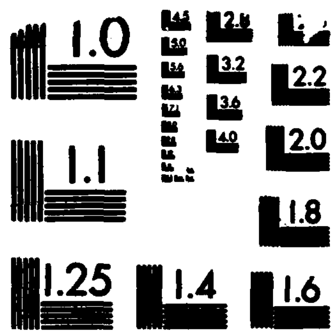


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

APPENDIX G

'WHY AND WHAT IS RELIABILITY-CENTERED MAINTENANCE?'
BY CHARLES SMITH OASD (I&L) BD (APRIL 23, 1976)

*NOTE: Both figures were redrawn to improve legibility

WHY AND WHAT IS RELIABILITY-CENTERED MAINTENANCE?

Background

For years, maintenance was a craft learned through experience and rarely examined analytically. While weapons systems have grown progressively more complex, what little critical thinking DoD has done about how to maintain and support those equipments has grown increasingly fragmented and less analytically sound. Today, when Defense spends in excess of $15 billion per year for maintenance, a fresh look at how we determine maintenance requirements is essential.

The airlines' maintenance problems are similar in many ways to DoD's. Because their profits as well as their performance are highly dependent on their maintenance practices, the airlines have a large incentive to maintain intelligently. Beginning in the late 50s, Stan Nowlan of United Air Lines started rethinking the aircraft maintenance process. Other airlines followed.

The UAL effort applied to maintenance the kind of analytic thinking often characterized as operations research. Nowlan, Howard Heap, Tom Matteson and others at UAL formally structured the problem of equipment support. They identified the assumptions which had underlain previous maintenance planning, examined the correctness of those assumptions, and revised them as appropriate. By the early 70s, they had evolved a philosophy of maintenance, which is broadly applicable.

The groups which promulgated significant portions of this philosophy for general use were Maintenance Steering Groups 1 and 2 of the Air Transport Association and Aerospace Manufacturers Association. Prior to issuance their work was reviewed and approved by the Federal Aviation Administration. Because the most widely circulated document is the report of Maintenance Steering Group 2, the thinking is often referred to as the MSG-2 approach or philosophy. The MSG-2 report was not a full treatment of the ideas and is often stigmatized (wrongly in our view) as being applicable only to commercial transport aircraft. Thus the more descriptive name, reliability-centered maintenance is preferred.

Definition

Reliability-centered maintenance philosophy defines the goal of maintenance for a specific piece of equipment, operating in a given material support environment, to be:

- o to enable the equipment to perform its assigned task
- o with a specified probability of success
- o at the lowest possible total cost for system operation and support

Charles Smith
OASD(I&L)BD
April 22, 1976

o over a period of time (usually the remaining service life of the equipment).

Applying this definition, the maintenance planner would in effect select the content and schedule of his preventive maintenance program, including inspection, as in a classic microeconomic constrained optimization problem by minimizing costs subject to the constraints of satisfying safety requirements and meeting operational performance goals.

However, solution of the optimization problem implicitly requires that one be designing maintenance plans for a set of equipments of stable design which have attained a steady-state pattern of independent failures. It also requires that cost and performance data be available for the full life cycle. Regrettably, neither of these conditions can be satisfied in real life.

o The very complexity of modern equipment is such that it is neither economical nor technically possible to ensure prior to service that every component will meet acceptable standards of performance and reliability without accepting such extreme overdesign as to make the equipment exorbitantly expensive and compromise its performance.

Usually, the design deficiencies which cause problems are not classical ones, but problems without significant prior history, often related to interfacing and interaction between components or subsystems. Thus, attempting to anticipate all such failures is impossible.

o Primary equipments will usually be operated for 20 to 30 years. We do have various techniques for compressing the life cycle of test items. However, to fully test equipments for an entire life cycle under completely representative environments, prior to entry into service, would require that the design, and thus the technology, be at least 30 years old. In an era when the half-life of some technologies is less than 6 years, this is unacceptable from both a performance and an economic standpoint.

Thus, it is unavoidable that throughout its service life the equipment being maintained will undergo a maturation process in which design deficiencies will appear. Product improvements to correct reliability and maintainability deficiencies as discovered must be included as a key element of the maintenance program. The average time between failures of initially unreliable complex equipments should increase over a period of many years as a result of modification activity.

Information to solve the optimization problem is almost totally unavailable when an initial maintenance program must be developed. The information becomes available only as it becomes progressively less useful because the equipment is aging toward obsolescence. What is required is a maintenance strategy which directly confronts the problem of making decisions given the unavoidably limited amount of information available and evolves as the equipment ages and more data become available.

The recognition that limited information necessitates a leap from maintenance plans to evolutionary maintenance strategies is one of Nowlan and Matteson's two most significant contributions to maintenance program development.

Efficiency and Reliability-Centered Maintenance

In designing a maintenance strategy, the two goals of effectiveness and efficiency are separable and non-contradictory, if one specifies effectiveness measures before trying to measure efficiency. Thus, optimization toward effectiveness does not preclude efficiency but merely defines what one should be efficient in doing.

The measure of maintenance effectiveness is the reliability with which the maintenance process delivers a satisfactorily operating weapon system which continues to operate. In the very short term, maintenance cannot improve upon the reliability that is inherent in the design of the hardware, and thus maintenance effectiveness at any point in time is limited by inherent reliability.

For the long term, if we define "maintenance" narrowly to exclude identification, design, and implementation of reliability improvement modifications, then maintenance effectiveness is the extent to which delivered reliability approaches the inherent reliability of the weapon system. If we expand the definition of "maintenance" to include identification, design and implementation of reliability improvement modifications, then we can measure long-term maintenance effectiveness in terms of delivered operational reliability, unconstrained by the inherent hardware reliability existing at any specific point in time.

Hardware reliability is precisely definable with a reasonably well-developed engineering and statistical basis. Measures of operational weapon system performance are not always available. However, one can structure the relationship between overall system performance and the reliability of individual equipments within the system. Analysis of equipment reliability, in large part, should drive the decisions about the work content of the maintenance program.

In practice, it is very difficult to distinguish between deficiencies in delivered operational reliability attributable to unsatisfactory inherent reliability and those due to poor maintenance execution. Thus, the means to attack both problems should be given to a maintenance manager who is held responsible for maintenance effectiveness in terms of delivered operational reliability.

Efficiency can be increased by eliminating unnecessary or counter-productive tasks -- an explicit goal of reliability-centered maintenance strategies. However, assuming that the work content has been properly defined, maintenance efficiency is a function of:

- maintainability dictated by the hardware design, that is, the minimum effort required to accomplish each maintenance task,

o discipline in eliminating maintenance effort in excess of that necessary, and

o labor productivity (efficiency in the narrow sense) in performing the essential maintenance tasks.

Maintainability is harder to quantify than reliability. In general, maintainability is addressed largely in terms of accessibility (with emphasis being given to those areas requiring frequent access), and provision for diagnosis of failures. Similarly, success in enforcing cost discipline by preventing addition of unnecessary or counterproductive tasks and controlling "featherbedding" is hard to measure absolutely, but may be effectively managed on a day-to-day basis by comparing relative performance over time.*

Reliability-centered maintenance focuses on the determination of work content in preventive maintenance (including inspection and product improvement). The resulting maintenance strategies address effectiveness or delivered reliability, while leaving the details of carrying out the tasks, i.e., efficiency, to the implementing organization.

Underlying Assumptions

In developing a basis for a reliability-centered maintenance strategy, the following seven assumptions implicit in prior thinking were identified, reviewed; and essentially reversed in every case.

(1) Former Assumption. Poor maintenance is the cause of safety/reliability problems.

Result of Review. Poor or inadequate maintenance may contribute to equipment failure but design is more important. If the design is inherently unreliable no amount of maintenance will solve the problem. At best, effective maintenance can keep equipment operating up to the reliability inherent in its design.

It is not desirable, and really not possible, to design perfectly reliable complex equipments. Thus, whenever possible equipments should be designed to degrade gracefully, i.e., to fail non-catastrophically or in a way that deterioration can be detected and corrected prior to a catastrophic failure. Recognition of this reality resulted in the move from safe-life design to fail-safe design of transport aircraft. (Interestingly, this change permitted a reduction in overdesign which resulted in a net weight saving.)

*In general, it would appear that self-reporting by a maintenance organization is an undesirable means of acquiring either maintainability or actual labor expenditure cost data. Instead, such data is probably best gathered by outside observers trained in labor accounting and time-motion study with the specific observations based on a sequential, stratified labor cost-sampling approach.

(2) Former Assumption. More maintenance is better.

Result of Review. Every maintenance action carries the potential of decreasing, rather than increasing, resistance to failure. Reducing the exposure of an equipment to unnecessary maintenance increases its operational reliability. Every potential maintenance action should be assessed carefully to ensure that it is likely to do more good than harm before it is adopted.

In an extreme example, a mechanic could leave a wrench inside an overhauled aircraft engine resulting in foreign object damage which would cause the engine to fail even if the overhaul were otherwise completely successful. (One Air Force study showed that 40% of the work necessary to restore a sample of F-4s to satisfactory condition was the direct result of failure induced by prior maintenance actions.)

(3) Former Assumption. Equipments wear out.

Result of Review. As pointed out vividly by Matteson, in general, the "bathtub curve" doesn't hold water. Single-celled equipments such as flex hoses, tires, brake pads, etc., do wear out. Complex systems composed of many single-celled equipments, such as radios, hydraulic control systems, etc., never "wear-out" so long as single-celled elements within the system are repaired, renewed or replaced as necessary.

To satisfactorily change-out or overhaul a complex equipment under the wear-out theory, the overhaul would be scheduled at the interval of failure of the most frequently failed single-celled equipment. Given that there is a known probability of damage inherent in any maintenance action and the infant mortality problems inherent in returning any overhauled or repaired equipment to service, "hard time" replacement or overhaul of equipments often becomes unjustifiable for reasons of reliability as well as of economics.

(4) Former Assumption. Inspection of non-failed equipments helps to anticipate failure.

Result of Review. Inspection of non-failed equipments is useful in only two forms: (1) quick visual inspections of clearly visible random gross discrepancies (zonals) and (2) specific inspections relating to a known failure mode in which inspection can detect something which correlates directly with reduced resistance to failure. An examination of history suggests that almost nothing is learned by other, less precisely defined, inspections of non-failed equipments.

For example, in United and American Air Lines' experience with the P&W R-2800 and Curtiss Wright R-3350 engines, the conclusions drawn by general "technical" inspections were usually erroneous. The inspectors identified large numbers of what they believed to be gross deficiencies in R-2800s while they could find only a few deficiencies in

R-3350s. The R-2800s were in fact far more reliable than the R-3350s and most of the R-2800 repairs were, in fact, unnecessary or counter-productive.

Inspection of failed equipments by qualified technical persons, on the other hand, can be highly fruitful because the problem is limited to that of finding the causes of a specific failure vice hypothesizing an infinite range of possible relationships.

(5) Former Assumption. Analysis of detailed maintenance history is prerequisite to managing a maintenance program.

Result of Review. Two distinct types of field maintenance experience should trigger action to revise a maintenance program.

- A one-time catastrophic (or near catastrophic failure) which identifies a previously unnoted functional failure requiring prompt action to avert possible repetition. (Items in this category require no historical data accumulation to surface.)

- A trend in which a specific equipment's reliability or maintenance cost crosses some sort of threshold. (Items in this category should ideally have actuarial history kept on them as well as sampled maintenance cost data, where appropriate. Cost should be considered in establishing the level of detail for such data.)

In both cases the only effective response is for an engineer to investigate the failed equipment. A request for specific additional data from the field may occasionally be helpful, but to collect massive quantities of historical data on every maintenance action on every equipment as is often requested by aircraft manufacturers (and actually attempted by the Department of Defense), merely generates unmanageable quantities of unedited, unanalyzed data.

(6) Former Assumption. The application of statistical methods to reliability is clearly understood.

Result of Review. Most statistical analyses of reliability have assumed inapplicable underlying models, never defined what constitutes a failure, and failed to address the realities of data quality (or the lack thereof). Not surprisingly, their results are often erroneous. Specific refinements in defining failure and measuring and interpreting it statistically were prerequisite to any reasonable maintenance analysis, and specifically to developing and implementing reliability-centered maintenance strategies.

A typical example of these problems is Bassin's analysis of the contribution of overhaul to submarine diesel engine reliability. 1/

1/ W.M. Bassin, "Increasing Hazard Functions and Overhaul Policy," Annals of Assurance Sciences, 1966.

In this paper, no distinction was made between failures requiring that a component be scrapped, failures requiring that a component be repaired, and imputed failures when a component was erroneously declared to have failed by an inspector without specific criteria while still functional. Further, Bassin chose an inappropriate underlying distribution of failures for his analysis. Bassin concluded that overhauls contributed significantly to increased reliability of diesel engines. As pointed out by Ascher 1/, when an approach recognizing different kinds of failure and an underlying distribution which fitted the data (and reliability-centered theory) was used, Bassin's conclusion was proven in error; in fact, the overhauls degraded reliability.

(7) Former Assumption. Where data is limited, informed engineering guesses cannot be improved upon.

Result of Review. While certain subjective judgments are essential and unavoidable, they should be kept to the minimum and made in a carefully structured framework so that such subjective judgments are clearly identifiable and trackable to assure consistency and permit rapid precise response to feedback. Discipline should be imposed both in the logical sequence of the decision process and in the subjective portions of the engineering analysis supporting the decision making. This perceived need for a formally structured decision logic was Nowlan and Matteson's second major contribution to maintenance program design.

Results

Based upon all these new insights, UAL developed two products:

(1) A formalized decision logic to identify the maintenance tasks to be applied based upon the design of the equipment. The attached diagrams illustrate the process for choosing among "hard-time" change-out (HT), "on-condition" change-out (OC), and "condition-monitoring" (CM) of a functional component. (Decisions in this process are based primarily on engineering information and judgment.) This process does not eliminate subjective judgment, but reduces it to a minimum and enforces consistency in its application. This process also provides feedback to the designer about basic design problems of a safety/reliability nature prior to test.

(2). An orderly process to evolve the maintenance program as more is learned about the characteristics of the equipment as it ages. This process structures a minimum maintenance data collection and analysis effort and establishes decision criteria so as to vary the intervals of scheduled maintenance for an item, change the type of maintenance applicable, and identify areas requiring product improvement. (Decisions in this process are based primarily on statistical information and procedures.)

1/H. Ascher and H. Feingold, Annals of Assurance Sciences, July 1969.

The result of applying this improved methodology to commercial aircraft maintenance strategy development was a marked reduction in the cost of maintenance with equal or better operational reliability. The commercial airlines experienced a 30% reduction in then-year dollar maintenance cost per flying hour over the decade 1963-73. When adjusted for inflation, the real reduction is impressive.

The logic is fully applicable in the military environment. Two studies prepared by the Center for Naval Analyses, using data exclusively from tactical aircraft, show a potential 50% reduction in the frequency of depot maintenance of the Navy's F-4s and a potential 53% reduction in the cost of depot maintenance of the Navy's aircraft gas turbine engines. Both of these reductions in cost would be directly accompanied by increased reliability of the subject equipment.

The U.S. Army Air Mobility Research and Development Laboratory independently appears to have arrived at much the same point of view. Their studies, of which the rest of the Army seems unaware, have shown the full applicability of these principles to helicopters, and potential savings and safety and operational improvements greater than the Navy's studies.

The discipline of the new methodology also permits the user for the first time to objectively size his preventive maintenance requirement. As a result, DoD has a rational basis for programming and budgeting to meet this requirement.

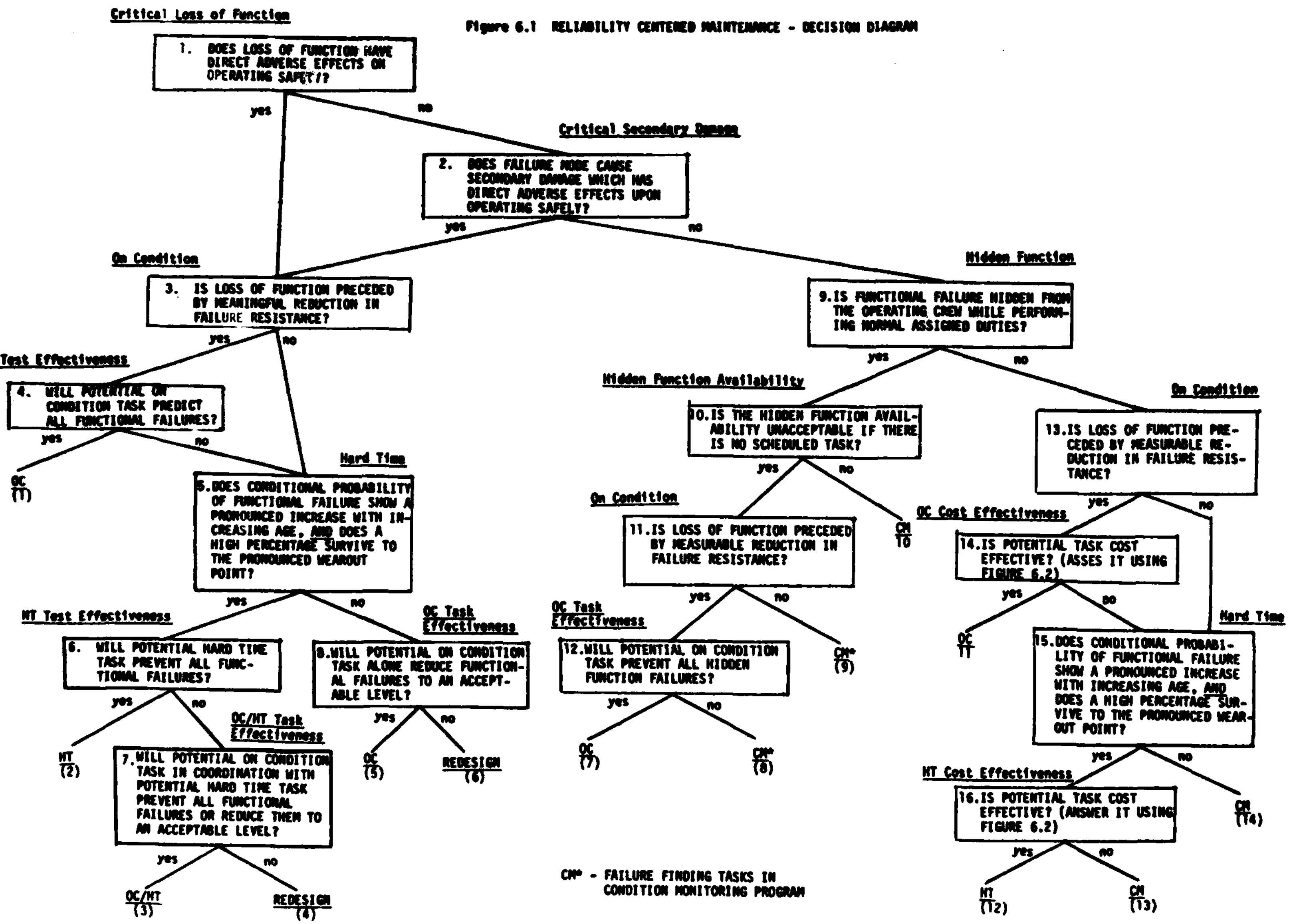
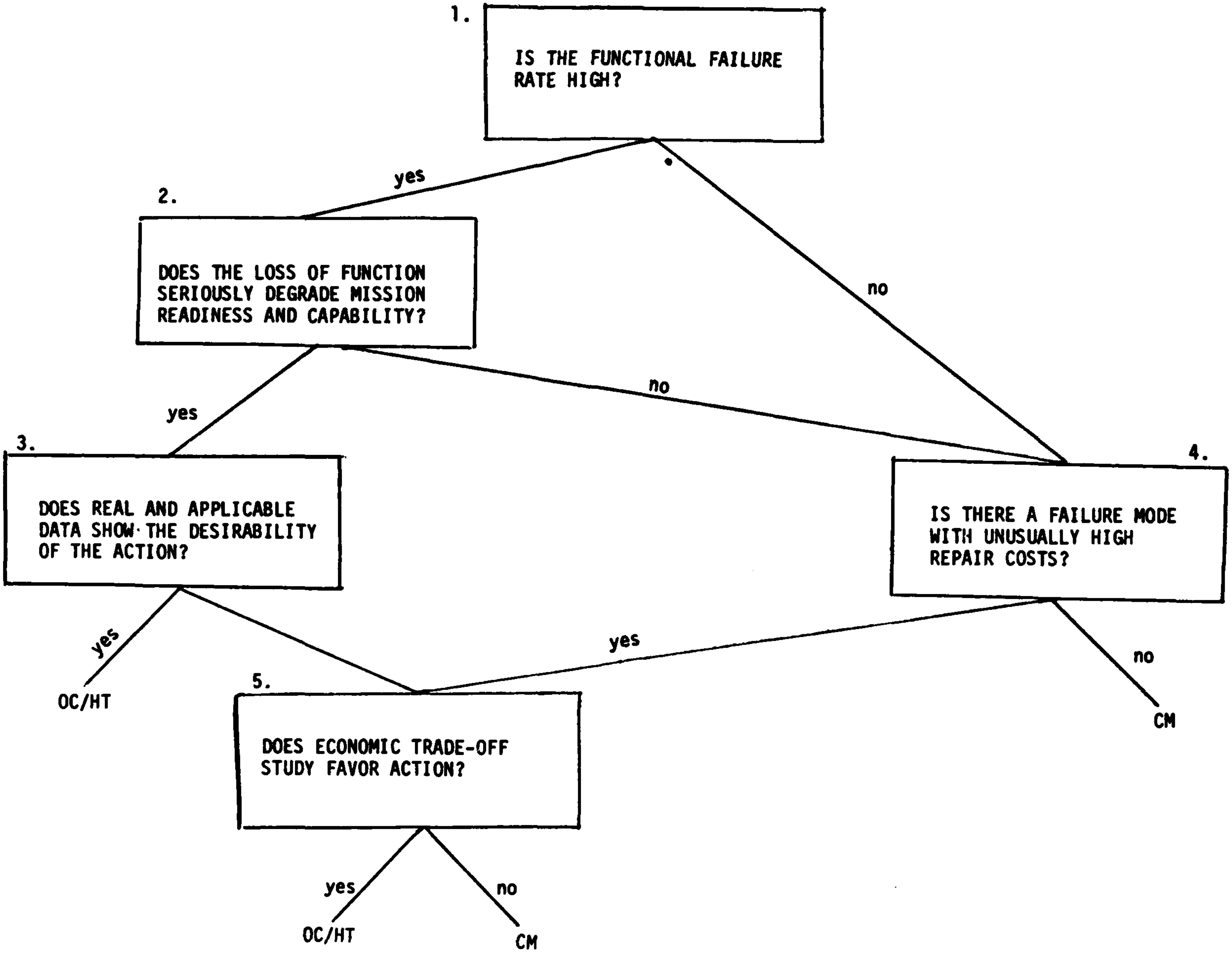


Figure 6.1 RELIABILITY CENTERED MAINTENANCE - DECISION DIAGRAM

Figure 6.2 -- COST EFFECTIVENESS DECISION DIAGRAM



APPENDIX H

GLOSSARY OF ABBREVIATIONS/ACRONYMS/TERMS

APPENDIX H

GLOSSARY OF ABBREVIATIONS/ACRONYMS/TERMS

A	AMPERES
ADCOM	AIR DEFENSE COMMAND
ADP	AUTOMATIC DATA PROCESSING
AEA	AMERICAN ELECTRONICS ASSOCIATION
AEGIS	AIRBORNE EARLY WARNING GROUND ENVIRONMENT INTEGRATION SYSTEM
AF	AIR FORCE
AFB	AIR FORCE BASE
AFCC	AIR FORCE COMMUNICATIONS COMMAND
AFCSC	AIR FORCE CRYPTOLOGIC SUPPORT CENTER
AFLC	AIR FORCE LOGISTICS COMMAND
AFWL	AIR FORCE WEAPONS LABORATORY
AFP	AIR FORCE PAMPHLET
AFR	AIR FORCE REGULATION
AIA	AEROSPACE INDUSTRIES ASSOCIATION
ALC	AIR LOGISTICS CENTER
AMBER	REDUCED OPERATIONAL MISSION CAPABILITY CONDITION
ATE	AUTOMATIC TEST EQUIPMENT
BIT	BUILT-IN-TEST
C^3I	COMMAND, CONTROL, COMMUNICATIONS AND INTELLIGENCE
CDRL	CONTRACT DATA REQUIREMENTS LIST
CE	CIVIL ENGINEERING
CE	COMMUNICATIONS-ELECTRONICS
CEM	COOLING ENVIRONMENTAL MONITOR
CEMIRT	CIVIL ENGINEERING MAINTENANCE, INSPECTION AND REPAIR TEAM
CFM	CUBIC FEET PER MINUTE
CG	COMMUNICATIONS GROUP
COC	COMBAT OPERATIONS CENTER
COMM	COMMUNICATIONS
COMSEC	SECURE COMMUNICATIONS
CONT	CONTROL
CONUS	CONTINENTAL UNITED STATES
CORE	CENTRAL PORTION OF THE BUILDING
CPU	CENTRAL PROCESSOR UNIT
CRT	CATHODE RAY TUBE
CYBER	AN/FYK013 COMPUTER
DGP	DATA GATHERING PANEL
DIG	DIGITAL
DoD	DEPARTMENT OF DEFENSE
DTL	DATALINE
ECU	ENVIRONMENTAL CONTROL UNIT
EIA	ELECTRONIC INDUSTRIES ASSOCIATION
EMP	ELECTROMAGNETIC PULSE
ESC	ELECTRONIC SECURITY COMMAND
ESD	ELECTRONIC SYSTEMS DIVISION
ESR	EQUIPMENT STATUS REPORT
FIIN	FEDERAL ITEM IDENTIFICATION NUMBER
FMS	FACILITY MANAGEMENT SYSTEM
FSN	FEDERAL STOCK NUMBER

GCA	GROUND CONTROLLED APPROACH
GEN	GENERATOR
GEODSS	GROUND-BASED ELECTRO-OPTICAL DEEP SPACE SURVEILLANCE SYSTEM
GFE	GOVERNMENT FURNISHED EQUIPMENT
GPM	GALLONS-PER-MINUTE
GPSP	GENERAL PURPOSE SIGNAL PROCESSOR
HQ	HEADQUARTERS
HZ	HERTZ
JLC	JOINT LOGISTICS COMMANDERS
JSS	JOINT SURVEILLANCE SYSTEM
KVA	KILOVOLT-AMPERES
KW	KILOWATTS
MAG	MAGNETIC
MDCS	MAINTENANCE DATA COLLECTION SYSTEM
MG	MOTOR GENERATOR
MIL	MILITARY
MMCO	MAINTENANCE MONITOR CONSOLE OPERATOR
MMICS	MAINTENANCE MANAGEMENT INFORMATION AND CONTROL SYSTEM
MWN	MISSILE WARNING
MWS	MISSILE WARNING SQUADRON
NAVAIDS	NAVAGATIONAL AID SYSTEMS
NCO	NON COMMISSIONED OFFICER
NIIN	NATIONAL ITEM IDENTIFICATION NUMBER
NORAD	NORTH AMERICAN DEFENSE
NSIA	NATIONAL SECURITY INDUSTRIES ASSOCIATION
NSN	NATIONAL STOCK NUMBER
PAVE PAWS	AN/FPS-115 PHASED ARRAY RADAR EARLY WARNING SYSTEM
PM	PERIODIC MAINTENANCE
PPFS	PRODUCT PERFORMANCE FEEDBACK SYSTEM
PPM	PARTS PER MILLION
RAC	RELIABILITY ANALYSIS CENTER
RADC	ROME AIR DEVELOPMENT CENTER
RAPCON	RADAR APPROACH CONTROL
RCL	AN/OK339 RADAR CONTROLLER
RCM	RELIABILITY CENTERED MAINTENANCE
RED	NON OPERATIONAL MISSION CAPABILITY CONDITION
RMS	ROOT MEAN SQUARED
ROCC	REGIONAL OPERATIONAL CONTROL CENTER
RPIE	REAL PROPERTY INSTALLED EQUIPMENT
RPM	REVOLUTIONS PER MINUTE
RSR	OPERATIONAL STATUS REPORT
R-12	REFRIGERANT NUMBER TWELVE FLUOROCARBON
SAC	STRATEGIC AIR COMMAND
SA-ALC	SAN ANTONIO ALC
S-ALC	SACRAMENTO ALC
SC/A	SHIPBUILDERS COUNCIL OF AMERICA
SCD	STRATEGIC COMMUNICATIONS DIVISION
SD	SYSTEM DIRECTOR
SEEK IGLOO	LONG RANGE MINIMALLY ATTENDED RADAR
SOAP	SPECTROSCOPIC OIL ANALYSIS PROGRAM
SRD	SYSTEM REPORTING DESIGNATOR
SwRI	SOUTHWEST RESEARCH INSTITUTE

GLOSSARY OF ABBREVIATIONS/ACRONYMS/TERMS (continued)

SYNC	SYNCHRONIZE
TAC	TACTICAL AIR COMMAND
TO	TECHNICAL ORDER
TOR	TACTICAL OPERATIONS ROOM
TRIC	TRANSACTION IDENTIFICATION CODE
UPS	UNINTERRUPTABLE POWER SUPPLY
VAMOSC	VISIBILITY & MANAGEMENT OF OPERATION AND SUPPORT COST
WEMA	WESTERN ELECTRONIC MANUFACTURERS ASSOCIATION (NOW AIA)
WPAFB	WRIGHT PATTERSON AFB
WUC	WORK UNIT CODE

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